DOCUMENT RESUME

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ABSTRACT

This set of individualized learning modules on transistor theory is one in a series of modules for a course in basic electricity and electronics. The course is one of a number of military-developed curriculum packages selected for adaptation to vocational instructional and curriculum development in a civilian setting. Two modules are included in the set: (1) Basic Transistor Theory and (2) Multi-Element Vacuum Tubes. Each module is comprised of individual lessons. Each lesson follows a typical format including a lesson overview, a list of study resources, the lesson content, a programmed instruction section, and a lesson summary. (Progress checks are provded for each lesson in a separate document, CE 026 582.) (LRA)

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ED190895

CHIEF OF NAVAL EDUCATION AND TRAINING

1 APRIL 1977

Military Curricula for Vocational & Technical Education

BASIC ELECTRICITY AND ELECTRONICS.

MODULE 21 BASIC TRANSISTOR THEORY
MODULE 21T MULTI-ELEMENT VACUUM TUBES

STUDY BOOKLET

CE 026 580

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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THE NATIONAL CENTER FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
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Springfield, IL 62777
217/782-0759

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The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL

Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

OVERVIEW

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE

Basic Transistor Theory

In this module you will learn how to identify the two types of transistors, how to identify the three leads of a transistor, and how a transistor can be compared to a variable resistor. You will learn the voltages required for conduction of the two types of transistors (this is called bias) and the maximum output signal amplitude possible from a transistor circuit. You will also be able to identify six basic transistor circuits, their functions, and two classes of bias for operation.

This module has been divided into the following five lessons:

Lesson I	-	Basic Transistor Theory
Lesson II	-	Transistor Biasing
Lesson III	-	Basic Transistor Amplifier Functional Analysis
Lesson IV	-	Basic Transistor Amplifier Configurations
Lesson V	-	Basic Transistor Amplifier Circuit Analysis

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE

LESSON 1

BASIC TRANSISTOR THEORY

1 April 1977

OVERVIEW
LESSON I

Basic Transistor Theory

In this lesson you will begin your study of transistors. You will learn how to distinguish between the two basic types of three-element transistors and identify each of the elements as shown on the schematic symbol. You will learn how they function and compare them to a variable resistor.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21.1.42 When the student completes this course, he will be able to TROUBLESHOOT an audio amplifier training device, given the required test equipment, schematic diagram, and a prefaulted audio amplifier. Faults to be limited to open or shorted components; no more than one fault per problem. Remove/replace a similar component on a practice card. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21.1.42.1 COMPARE the operation of a transistor to a variable resistor, by selecting the correct statement from a group of four or identifying the correct circuit configuration with 100% accuracy.

21.1.42.1.1 SELECT the schematic symbol for the component which functions most like a transistor from a choice of four schematic symbols of non-active components. 100% accuracy is required.

21.1.42.1.2 ANALYZE the effects of a change in circuit resistance on current and voltage by selecting the correct voltage/current relationships from a group of four, given a schematic diagram of a circuit containing a source connected to a variable resistor in series with a load. 100% accuracy is required.

21.1.42.1.3 DETERMINE the resultant qualitative voltage drop across a transistor when that transistor's conductivity increases/decreases, by selecting the correct choice from a list of four possible choices. 100% accuracy is required.

OVERVIEW

21.1.42.1.4 IDENTIFY the schematic symbol for a three element PNP transistor by selecting the correct symbol from a set of four choices. 100% accuracy is required.

21.1.42.1.5 IDENTIFY the schematic symbol for a three element NPN transistor by selecting the correct symbol from a set of four choices. 100% accuracy is required.

21.1.42.1.6 IDENTIFY the name of each lead on a transistor schematic symbol by matching the correct name, from the list provided, with each lead as numbered on the schematic symbol shown. 100% accuracy is required.

21.1.42.1.7 IDENTIFY the collector, base, and emitter leads on an actual transistor, given a transistor. 100% accuracy is required.

21.1.42.1.8 IDENTIFY the major current flow through an NPN/PNP transistor by selecting the schematic symbol for an NPN/PNP transistor which correctly illustrates the major current flow from a list of transistor schematic symbols. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON 1

Basic Transistor Theory

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Job Program Twenty One-1 "Transistor Identification"
Progress Check

Additional Material(s):

Audio/Visual Program Twenty One-1 "Basic Transistor Theory"

Enrichment Material(s):

Electronics Installation and Maintenance Book, Electronic Circuits, NAVSHIPS 0967-000-0120, section 5.

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING SUPERVISOR; HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

SUMMARY
LESSON I

Basic Transistor Theory

Transistors were invented at Bell Telephone Laboratories in 1948, and have practically replaced tubes in modern electronic equipment.

Functionally, the transistor can be compared to a variable resistor because it is able to vary the current through the circuit it is in. (The transistor is a current amplifying device.) Because we are mostly concerned with current, when using transistors we speak of a transistor's conductivity.

Transistor action is similar to a variable resistor in a series regulator circuit. Increasing the resistance decreases the current through the variable resistor but increases the voltage across the variable resistor. The transistor, in essence, does the same thing. As its conductivity increases, the voltage across the transistor decreases.

A circuit will normally show the tie point between the circuit and its power source as a line, a line with an arrowhead, or a line with a dot with a +, -, Vcc, -Vcc, or a letter of the alphabet (See Figure 1).

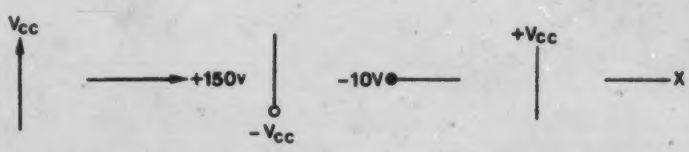


Figure 1

As shown in Figure 1, the line can be up, down, or on its side, but will always indicate a tie point between circuit and power supply.

The basic transistor is comprised of three elements: the emitter, the base, and the collector. Schematically, the transistor looks like the illustration in Figure 2.

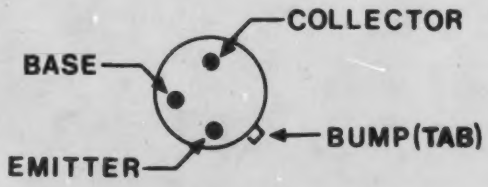
Transistor Elements

Figure 2

There are two types of three element transistors, NPN and PNP. The NPN will have the arrow on the emitter NOT POINTED IN. The PNP will have the arrow POINTED IN from the PERIMETER. NPN transistors will be used mainly with positive power supplies, and PNP transistors will be used with negative power supplies. In either case the direction of current flow will always be against the arrow. See Figure 3.

Figure 3

Transistor elements can be easily identified by some key or mark that will be placed on it by the manufacturer. This key or mark will almost always be nearest to the emitter. See Figure 4.



Transistor Lead Identification

Figure 4

Figure 4 shows the underside of a common transistor. The small bump identifies the emitter and, going clockwise, we have the base, then the collector. Other base diagrams and transistor data are given in reference books such as Electronics Information Maintenance Bulletin, transistor manuals, and equipment technical manuals.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON I

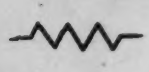
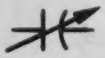
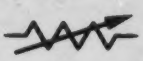
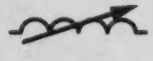
Basic Transistor Theory

TEST FRAMES ARE 8 AND 11. GO FIRST TO TEST FRAME 8 AND SEE IF YOU CAN ANSWER THE QUESTION. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. Transistors were invented at the Bell Telephone Laboratory in 1948. Over the years it has been discovered that the transistor can do almost anything a tube can do with greater efficiency, dependability and at a lower cost, so it's no great surprise that transistors have practically replaced vacuum tubes in modern electronic equipment.

Functionally the transistor can be compared to a variable resistor because it is able to vary the current through the circuit it is in. The big difference is that the transistor is an amplifying device, the resistor is not. (More about this later.)

Which of the following schematic illustrations can most readily be compared to the transistor?

a.  b.  c.  d. 

- -

c.

2. When we speak of resistors, we talk in terms of resistance or resistivity. With transistors we talk in terms of conductance or conductivity because a transistor is primarily a current amplifying device. (Conductance is the reciprocal of resistance.) Transistors also amplify voltage, but remember, current through resistors is the means by which the voltage drop is produced.

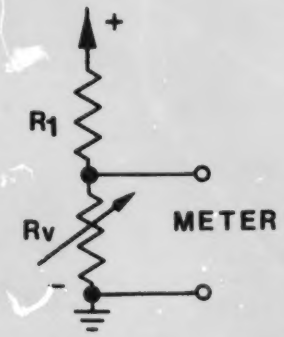
When speaking of transistors, we talk in terms of _____.

- -

conductance or conductivity (or words to that effect)

3. Transistor action can be compared to the action of a variable resistor in a series regulator circuit. (See the lesson on power supply regulators.) Let's review this circuit. A variable resistor (Rv) is placed in series with a fixed resistance.

When Rv is increased, what happens to the voltage <u>across</u> Rv and the current <u>through</u> Rv?



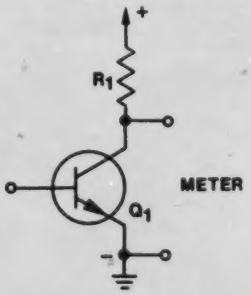
a. Voltage decreases and current increases.
b. Voltage increases and current decreases.
c. Voltage decreases and current decreases.
d. Voltage increases and current increases.

- -

b. Voltage increases and current decreases.

4. The transistor, in essence, works the same way. As the resistance of the transistor decreases, conduction increases and the voltage across the transistor decreases. Sound familiar?

What happens if the transistor's resistance increases?



a. Conduction increases and voltage across the transistor increases.
b. Conduction decreases and voltage across the transistor increases.
c. Conduction decreases and voltage across the transistor decreases.
d. Conduction increases and voltage across the transistor decreases.

- -

b. Conduction decreases and voltage across the transistor increases.

5. Take another look at the circuit in Frame 4. You will notice an arrow pointing upward with a plus next to it. This arrow does not indicate an output. It indicates a tie point between the circuit and its voltage source. This arrow may point up, down, or sideways, but will be shown with a +, -, Vcc, -Vcc (Vcc is an abbreviation for power source), or a letter of the alphabet. When a + or - is used the voltages are normally shown. Some examples of this are shown in Figure 1.

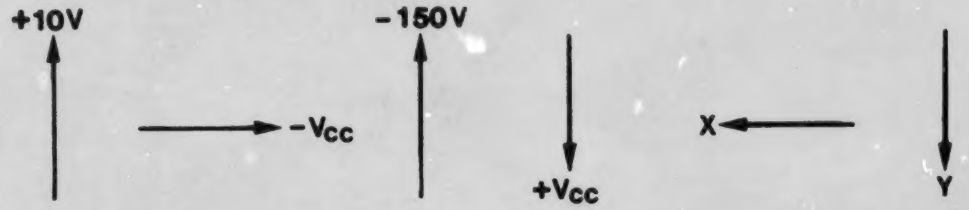


Figure 1

There isn't always an arrow head on the line indicating the power source tie point. You may find a dot or just a line as shown in Figure 2.

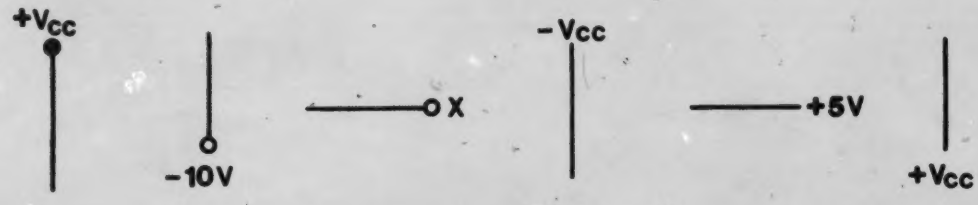


Figure 2

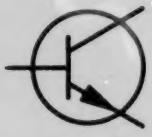
In any case, at the indicated point the circuit is tied to the power supply.

In a circuit schematic, a power supply tie point (is/is not) indicated by a line going to a +, -, Vcc, -Vcc, or letter and (indicates/doesn't indicate) a physical connection with the power supply at that point.

- -

is, indicates (in that order)

6. The basic transistor is comprised of three elements. Schematically, the three element transistor is very easy to identify. It resembles the letter "Y".



The easiest element to identify is the emitter; it will always be denoted by an arrow.

The base is also easy to identify; at its connecting point it forms a T.

The final element, the collector.

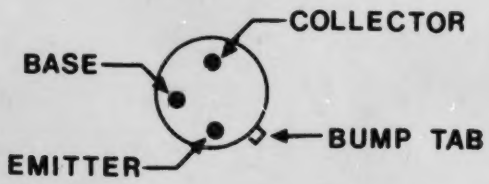
Match the correct element names with the numbers on the schematic illustration shown.

1. ____ a. Emitter
2. ____ b. Base
3. ____ c. Collector

- -

1. b. Base
2. c. Collector
3. a. Emitter

7. The physical elements of the transistor are also easily identified. In one of the most common base systems there is some key or mark (a bump, a dot, a notch, etc.) on the transistor to show where the emitter is located. This "mark" is normally close to the emitter. See Figure 3.

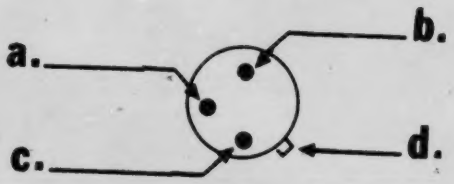


Transistor Lead Identification

Figure 3

Turning the transistor so you are looking at its underside, the first element clockwise from the emitter is the base and the next is the collector. This does not identify the "type" of transistor (NPN or PNP), only the elements; you have to look in the manuals to find that data. Other base diagrams are shown in Job Program Twenty One-I, Electronics Information Maintenance Bulletin, transistor manuals, and equipment technical manuals.

Label the parts of the transistor shown.



- -

a. base, b collector, c. emitter, d. bump (tab)

8. TEST FRAME

Which of the following statements about a transistor is most correct?

a. The element identification mark on a transistor is usually near the collector.
b. The element identification mark on a transistor will tell you which type it is.
c. The element identification mark on a transistor will usually be near the emitter.
d. The element identification mark on a transistor will usually be near the base.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

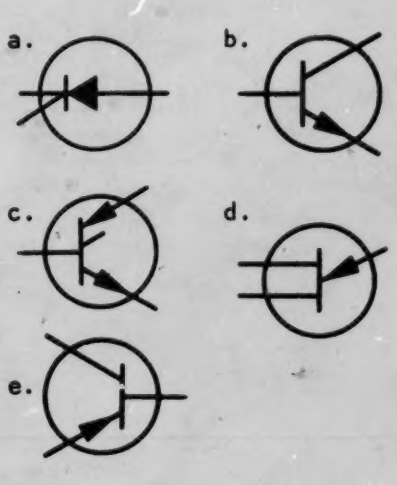
c. The element identification mark on a transistor will usually be near the emitter.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO TO TEST FRAME 11. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 8 AGAIN.

9. There are two types of three element transistors. In schematic diagrams they can be distinguished by the direction the emitter arrow points. The two types are NPN and PNP. The initials denote the electrical properties of these transistors. (P = positive, N = negative.) The initials are also an easy way to identify each. The initials NPN can mean the arrow is NOT POINTED IN and PNP can mean POINTED IN from the PERIMETER.

Which of the following symbols represents an NPN transistor and which is PNP?

_____ is NPN
_____ is PNP



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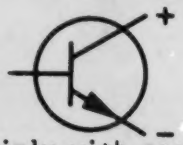
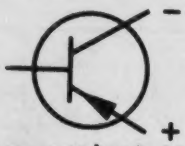
10. NPN transistors will be used mainly with positive power supplies.



PNP transistors will be used mainly with negative power supplies.



In either case, current will flow <u>against</u> the arrow.

NOTE: Power supplies can be positive or negative. The basic difference is where the output is taken from with reference to ground. If the negative side of the power supply output is grounded, it's a positive power supply. If the positive line is grounded, it's a negative power supply.

What voltages on the emitter and collector of a transistor insure proper current flow within the transistor? (Select all correct choices.)

a. NPN - collector positive with respect to the emitter.
b. PNP - collector positive with respect to the emitter.
c. NPN - collector negative with respect to the emitter.
d. PNP - collector negative with respect to the emitter.

- -

a.; d.

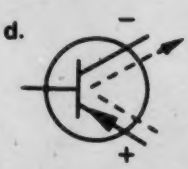
11. TEST FRAME

Which of the following illustrations is most correct? (The broken arrow indicates direction of current flow.)

a.

b.

c.

d. 

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

c.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON I MODULE TWENTY ONE. OTHERWISE, GO BACK TO FRAME 9 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 11 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

NARRATIVE
LESSON I

Basic Transistor Theory

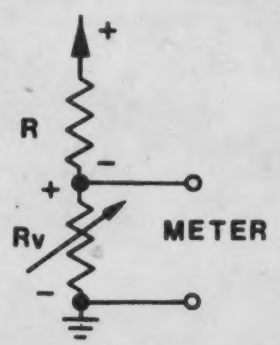
One of the great advances in electronics took place at Bell Telephone Laboratories in 1948 with the invention of the transistor. Since then, transistors have been developed that can do about anything a vacuum tube can do with greater efficiency, dependability, and generally a lot cheaper. It's no great surprise that transistors have practically replaced tubes in modern electronic equipment, so you're going to spend a lot of time studying them.

Functionally, the transistor can be compared to a variable resistor because it is able to vary the current through the circuit it is in. (The big difference is that the transistor is an amplifying device; the resistor is not.)

The transistor is primarily a current amplifying device. Transistor action can amplify voltage, but remember, current control is the means by which the voltage is varied. When we speak of resistors, we talk in terms of resistance or resistivity. With transistors we speak of conductance or conductivity; that is, the ability to carry current. Remember, conductance is the reciprocal of resistance ($\frac{I}{R}$).

The transistor action compares with the action of a variable resistor in a series regulator circuit. (See the lesson on power supply regulators.) Let's review this circuit. A variable resistor (Rv) is placed in series with a fixed resistance.

When Rv is increased what will happen to the voltage across Rv and the current through Rv?



a. Voltage decreases and current increases.
b. Voltage increases and current decreases.
c. Voltage decreases and current decreases.
d. Voltage increases and current increases.

b. (Review the Module on Power Supply Regulators if this is not clear to you now.)

The transistor, in essence, works the same way. As the conductivity of the transistor increases (its resistance decreases), the voltage across the transistor decreases. See Figure 1.

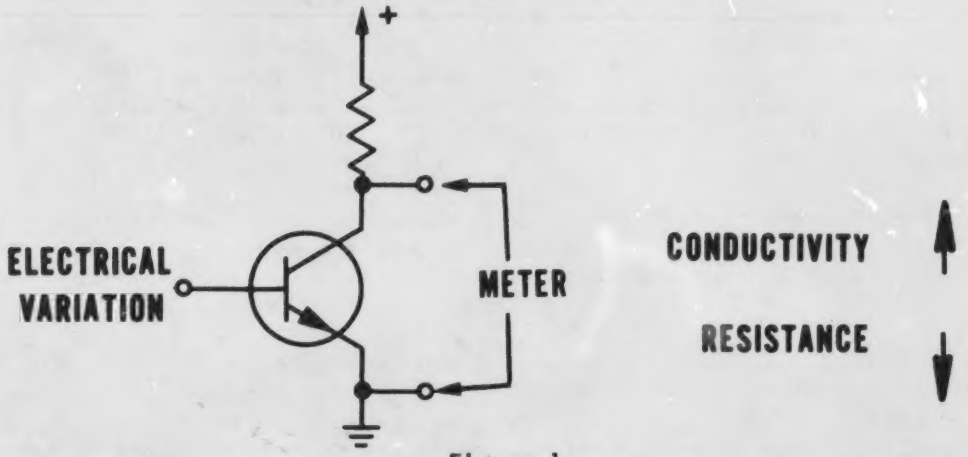


Figure 1

Take another look at Figure 1. You will notice an arrow pointing upward with a plus next to it. This arrow does not indicate an output. It indicates a tie point between the circuit and its voltage source. This arrow may point up, down, or sideways, but will be shown with a +, -, Vcc, -Vcc (Vcc is an abbreviation for power source), or a letter of the alphabet. When a + or - is used the voltages are normally shown.

Some examples of this are shown in Figure 2.

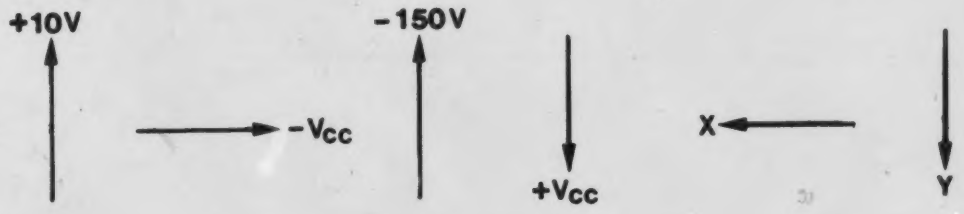


Figure 2

There isn't always an arrow head on the line indicating the power source tie input. You may find a dot or just a line as shown in Figure 3.

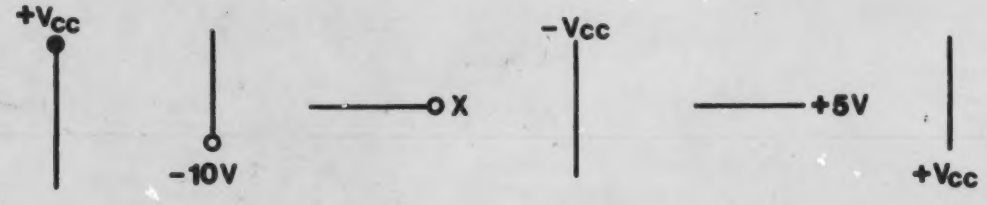


Figure 3

In any case, at the indicated point the circuit is tied to the power supply, and this is the point at which the circuit receives the power it needs in order to operate.

Before we go further on the operation of transistors, let's look at some of its physical characteristics.

The basic transistor is comprised of three elements. Schematically the three element transistor is very easy to identify. It resembles the letter "Y".

The easiest element to identify is the emitter.
The emitter will always be denoted by an arrow.

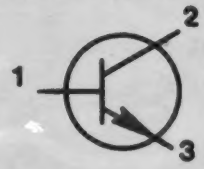
The base is also easy to identify. At its connecting point it forms a T.

The final element, through the process of elimination, is the collector.

Match the correct element names with the numbers on the schematic illustration shown.

1. ____
2. ____
3. ____

a. Emitter
b. Base
c. Collector



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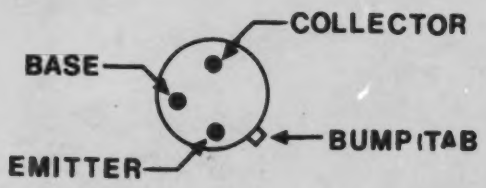
1. b. Base
2. c. Collector
3. a. Emitter

The elements of the transistor are also easily identified physically. There is always a key or mark (a bump, a dot, a notch, etc.) on the transistor to show where the emitter is located, as shown in Figure 4.



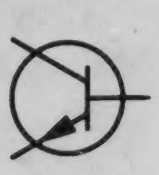
Transistor Lead Identification

Figure 4

(In most cases the key or mark will be close to the emitter). Figure 4 shows one of the most common transistor bases in use at this time. The illustration shows the transistor from its underside. The first element clockwise from the emitter is the base and the next is the collector. The key or mark on a transistor does not identify the type of transistor (NPN or PNP), only the elements; you have to look in a manual to find out the type. Other base diagrams are illustrated in Job Program Twenty One-I, Electronics Information Maintenance Bulletin., transistor manuals, and equipment instruction manuals.

There are two types of three element transistors. Their schematic symbols can be distinguished by the direction the emitter arrow points. The two types are NPN and PNP. These initials denote the electrical properties of these transistors (P = positive, N = negative). The initials are also easy ways to identify each. NPN can mean the arrow is NOT POINTED IN and PNP can mean the arrow is POINTED IN FROM THE PERIMETER.

The following symbols represent NPN and PNP transistors. See Figure 5.

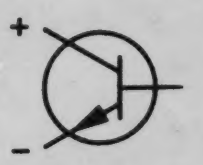


NPN

PNP

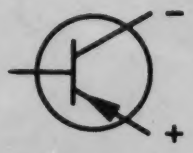
Figure 5

NPN transistors will be used mainly with power supplies with positive voltage outputs and



NPN

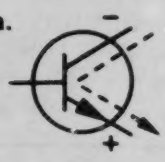
PNP transistors will be used mainly with negative power supplies, but in either case, current will flow against the arrow.



PNP

NOTE: Power supplies can be positive or negative. The basic difference is where the output is taken from with reference to ground. If it is taken above ground it's a positive power supply. If it's taken below ground it's a negative power supply.

Which of the following illustrations is most correct? (The dashed arrow indicates direction of current flow.)

a. 

b.

c.

d.

- -

c.

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BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE

LESSON II

TRANSISTOR BIASING

1 April 1977

OVERVIEW
LESSON II

Transistor Biasing

In this lesson you will learn about biasing and how it is used to control the conduction of a transistor. You will learn why the two types of transistors require voltages of opposite polarities and how to determine which transistor requires which polarity. You will study about the control functions of the transistor's base, the reason for using stabilization components, and how to determine the maximum amplification possible for a given amplifier.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21.2.42 When the student completes this course, he will be able to TROUBLESHOOT an audio amplifier training device, given the required test equipment, schematic diagram, and a prefaulted audio amplifier. Faults to be limited to open or shorted components; no more than one fault per problem. Remove/replace a similar component on a practice card. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21.2.42.3 DEFINE the function or purpose of (1) the transistor, (2) static/dynamic bias, and (3) stabilization in the conversion stage of an amplifier by selecting the correct statement from a list of four choices, only one of which is correct. 100% accuracy is required.

21.2.42.3.1 DEFINE static/dynamic bias by selecting the best statement from a list provided. 100% accuracy is required.

21.2.42.3.2 SELECT the PNP and the NPN transistor schematic symbols labelled with relative voltage polarities (bias) which will enable each of them to conduct, given sets of 4 schematics (one set for each type), one of which is properly polarized. 100% accuracy is required.

21.2.42.3.3 DETERMINE a transistor amplifier's maximum peak-to-peak output, given a transistor amplifier circuit with Vcc indicated and a list of four choices, only one of which is correct. 100% accuracy is required.

OVERVIEW

21.2.42.3.4 IDENTIFY the basic reason for providing stabilization in a transistorized circuit by selecting the correct statement from a set of four choices only one of which is correct. 100% accuracy is required.

21.2.42.3.5 IDENTIFY the stabilizing component(s) in a schematic diagram of a basic common emitter amplifier circuit by selecting the correct stabilizing component from a set of four choices only one of which is correct. 100% accuracy is required.

21.2.42.3.6 SELECT the name of the transistor element that controls current flow through the transistor, from a list of names including collector, emitter, and base. 100% accuracy is required.

21.2.42.3.7 ANALYZE the effects on the conduction of a PNP (NPN) transistor when a positive (or negative) input alternation is applied to the base by selecting from a choice of four statements only one of which is correct. 100% accuracy is required.

21.2.42.12 OBSERVE and MEASURE the bias and its effects on a transistor amplifier given a training device, an oscilloscope, and a multimeter. 100% accuracy is required.

21.2.42.13 OBSERVE the effects of temperature on the conduction of a transistor given a training device, and a multimeter. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON II

Transistor Biasing

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Audio/Visual Response Sheet Twenty One-II
Job Program Twenty One-II "Transistor Biasing"
Progress Check

Additional Material(s):

Audio/Visual Twenty One-II "Transistor Biasing"

Enrichment Material(s):

Electronics Installation and Maintenance Book, Electronic Circuits NAVSHIPS 0967-000-0120, section 5

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING SUPERVISOR; HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

SUMMARY
LESSON II

Transistor Biasing

Static Bias is defined as the DC potentials at the collector and the base with respect to the emitter necessary to establish a transistor's conduction level.

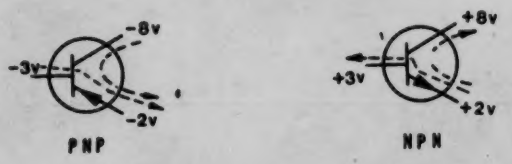
The transistor's emitter is always used as the reference point. In an NPN transistor biased for conduction, the base will be more positive than the emitter, and the collector will be more positive than the base and the emitter. In a PNP transistor biased for conduction, the base will be more negative than the emitter, and the collector will be more negative than the base and emitter. This is shown in Figure 1.

Figure 1

The voltages shown on the transistors' leads in Figure 1 were measured with respect to ground. To find the actual static bias voltages across the transistor's elements you must:

1. Subtract the emitter voltage from the base voltage for the base-emitter static bias voltage (Vbe).
2. Subtract the emitter voltage from the collector voltage for the collector-emitter static bias voltage (Vce).

The flow of current in a transistor will be against the arrow, as shown in Figure 2.

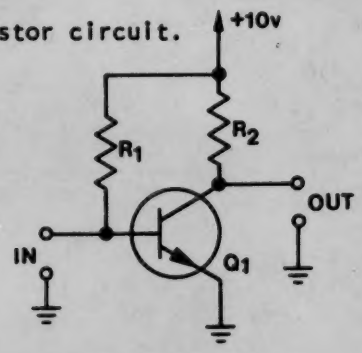


Current Flow in NPN and PNP Transistors

Figure 2

As you can see from Figure 2, no current flows between base and collector. The emitter current in both transistor types is a combination of both the base and collector currents.

Figure 3 shows an NPN transistor circuit.



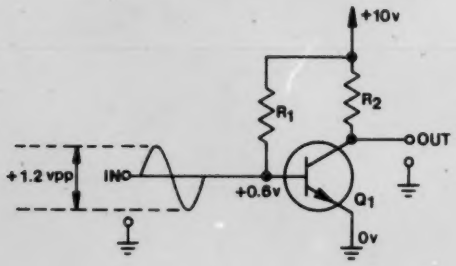
NPN Transistor Circuit

Figure 3

The voltage applied to the collector comes from the +10 volt supply through R2.

The base-emitter bias voltage is produced by the current flow from ground through the base-emitter, through R1, to the +10 volt supply. The base-emitter has a certain resistance which will produce a voltage drop across it. The amount of voltage will be determined by the amount of current R1 allows to flow in the base-emitter circuit. Changing R1's value changes the amount of current that flows in the base-emitter circuit giving us an easy way of changing base-emitter static bias voltage (Vbe).

The transistor's base is its controlling element. Changing the base-emitter circuit current, by changing the voltage applied to the base-emitter, will cause a change in transistor conduction. Because of transistor construction it only takes a few tenths of a volt across the base-emitter to make a large change in conduction in the collector-emitter circuit. See Figure 4.



NPN Transistor Circuit with Input Signal

Figure 4

A 1.2 volt peak-to-peak sine wave is applied to the base which, in this case, has a 0.6 volt D.C. static bias voltage on it. The sine wave will add to and subtract from the 0.6 volt DC static bias voltage causing the base voltage to vary between 0.0 volts and 1.2 volts, as shown in Figure 5.

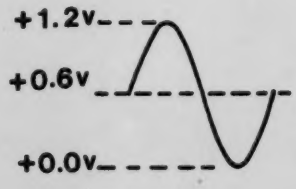


Figure 5

The changing potential caused by the input signal is called Dynamic Bias. Dynamic bias is the bias voltage on the base of a transistor with a signal applied and is a combination of the input signal and the static bias voltage.

A sine wave will cause maximum conduction in an NPN transistor during its positive variation and minimum conduction during its negative variation. The increase in conduction causes a decrease in the voltage across the transistor. Since voltage is what is seen on an oscilloscope, you will see a positive-going input as an amplified negative-going output. The sine wave's negative variation will show an amplified positive-going output. This is shown in Figure 6.

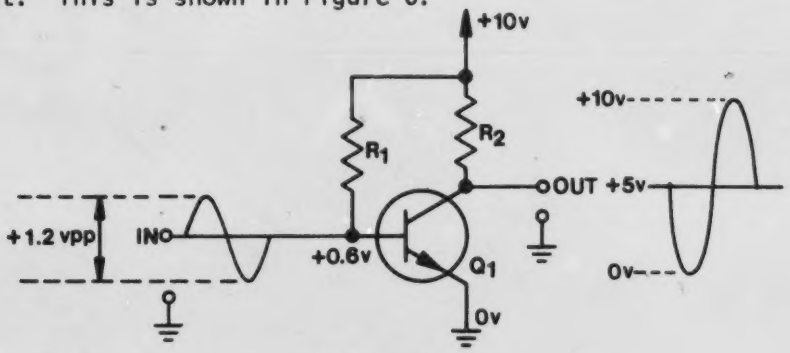


Figure 6

PNP transistors work the same. A positive-going input produces an amplified negative-going output.

The potential for the collector is called Vcc or collector supply voltage. Regardless of the amount of amplification, the peak-to-peak output voltage cannot exceed the value of Vcc.

Heat can easily destroy a transistor. For this reason transistorized equipment is normally located in air conditioned spaces. However, a transistor can create its own internal heat which can destroy it even though it may be in an equipment which is located in an air conditioned space.

In the fixed base bias circuit, Figure 7, the only control over static base-emitter current is the resistance of the base-emitter and R1's resistance.

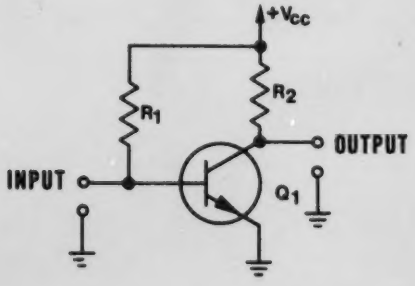
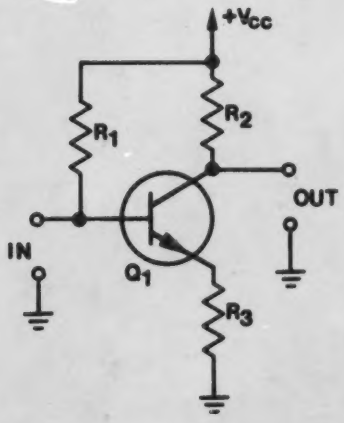


Figure 7

R1's resistance is fixed and will not change. However, Q1's base-emitter resistance will decrease if a certain temperature limit is exceeded. If the base-emitter resistance begins to decrease, more current will flow through the base-emitter increasing collector-emitter current flow. As the collector-emitter current flow increases it causes more internal heating of the transistor. The extra heat increases base-emitter current which increases collector-emitter current again producing more heat. Once started, this process, called thermal runaway, continues until the transistor destroys itself. Thermal runaway can be prevented by the addition of a stabilizing resistor, called an emitter resistor, between a transistor's emitter and ground as shown in Figure 8.

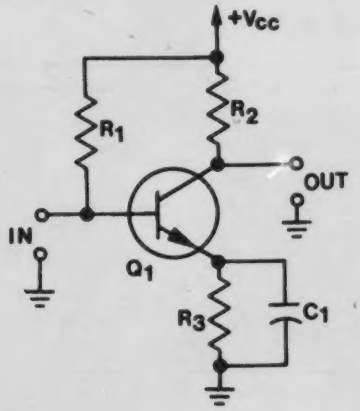


NPN Transistor Circuit with Emitter Resistor

Figure 8

Emitter resistor R3 has a large resistance as compared to the resistance of the base-emitter. Now, the base-emitter resistance is only a small percentage of the total base-emitter circuit resistance. If base-emitter resistance decreases from heat there will be practically no change in base-emitter current flow.

However, the emitter resistor causes degeneration (reduced signal amplification) as the signal developed across it is in phase with the input signal reducing dynamic bias. To prevent degeneration, an emitter by-pass capacitor (C1 in Figure 9) is added to shunt (by-pass) the degenerating signal voltage to ground without effecting the static bias voltage.



NPN Transistor Circuit with Emitter Resistor and Emitter By-Pass Capacitor

Figure 9

There is one other cause of thermal runaway which does not always occur as it is dependent on circuit design and application.

In some circuits it is possible for the transistor's base to build up a charge, positive for NPN and negative for PNP. In either case, the charge increases the transistor's forward bias. An increase in forward bias increases transistor conduction producing internal heating. The extra heat will further increase the charge again increasing forward bias and producing more heat from conduction. This cycle continues and we again have thermal runaway. To prevent this type of thermal runaway a resistor is placed between the transistor's base and ground to bleed off the charge as it forms. The resistor is shown as R3 in Figure 10.

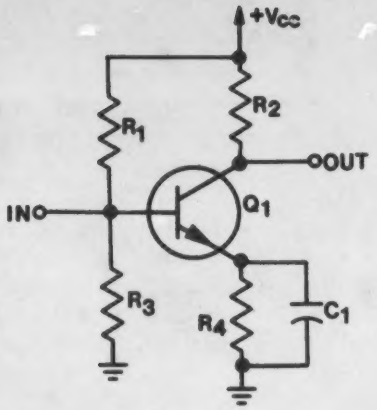


Figure 10

R3 will bleed off the charge that forms on Q1's base with very little effect on the base bias voltage, stabilizing the transistor.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

Transistor Biasing

TEST FRAMES ARE FRAMES 3, 6, 12, 15 AND 19. GO FIRST TO TEST FRAME 3 AND SEE IF YOU CAN ANSWER THE QUESTION. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. You know that transistors are amplifying devices! You also know there are two types (NPN and PNP). What you don't know are the various conditions necessary to make the transistor operate. Well, one of these conditions is called Static Bias. Static bias is defined as the D.C. potentials at the collector and base with respect to the emitter that are necessary to establish a transistor's conduction level.

Static bias may be defined as:

a. The A.C. potentials on the base and emitter leads that set the proper amount of conduction prior to the injection of a signal.
b. The A.C. potential on each lead that sets the proper amount of conduction prior to the injection of a signal.
c. The D.C. potentials at the collector and base with respect to the emitter necessary to establish a transistor's conduction level.
d. The D.C. potential on each lead that sets the proper amount of resistance after a signal has been applied.

- -

c. The D.C. potentials at the collector and base with respect to the emitter necessary to establish a transistor's conduction level.

2. We can start our discussion of bias by looking at static bias voltages and polarities for transistor conduction.

Think of the transistor's emitter as being a reference point. In an NPN transistor biased for conduction, the base will be more positive than the emitter, and the collector will be more positive than the base and the emitter. This is shown in Figure 1.

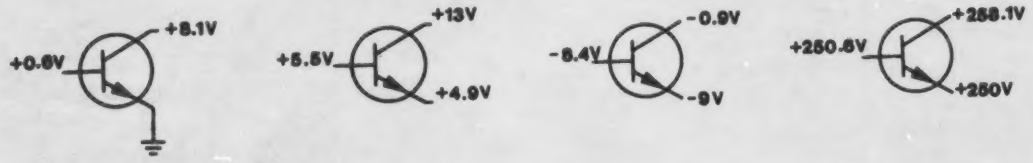


Figure 1

These transistors are forward biased (conducting).

The type of transistor shown in Figure 1 has these voltage requirements; the collector is 8.1 volts more positive than the emitter, the base is .6 volts more positive than the emitter. As you can see from Figure 1, many different voltages and polarities can meet this transistor's voltage requirements.

In an NPN transistor biased for conduction the emitter will have the (most/least) positive potential applied to it.

- -

least

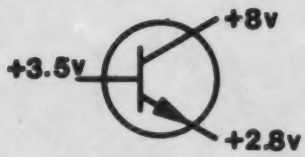
3. TEST FRAME

Which of the following transistors has the correct static bias potentials applied for conduction?

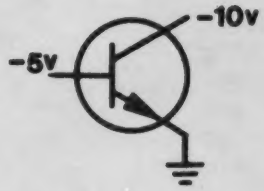
a.

c.

b.



d.



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(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER AT THE TOP OF THE NEXT PAGE.)

b.

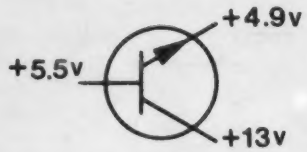
IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 6. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 3 AGAIN.

4. The voltages on the transistor's leads are measured with respect to ground. However, to determine the static bias voltage and polarity you must subtract the voltage on one lead from the voltage on the other lead. For example:

Vcollector = +13V

Vbase = +5.5V

Vemitter = +4.9V

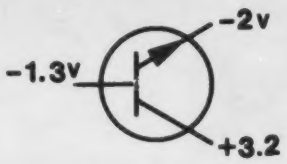


Base-Emitter static bias voltage (Vbe) = Vbase - Vemitter
= +5.5V - (+4.9V)
= +.6V

Collector to Emitter static bias voltage (Vce) = Vcollector - Vemitter
= +13V - (+4.9V)
= +8.1V

To obtain the correct polarity of the static bias voltage you must remember to always subtract the emitter voltage from the base or collector voltage.

For the following transistor the static bias voltages are; Base-Emitter (Vbe) = _____, Collector-Emitter (Vce) = _____.



- -

+.7V, +5.2V (in that order)

5. In the previous lesson you learned that the current flow in a PNP transistor is the reverse of that in the NPN transistor. This requires that opposite polarities of static bias voltages be applied to the PNP's leads. This is shown in Figure 2.

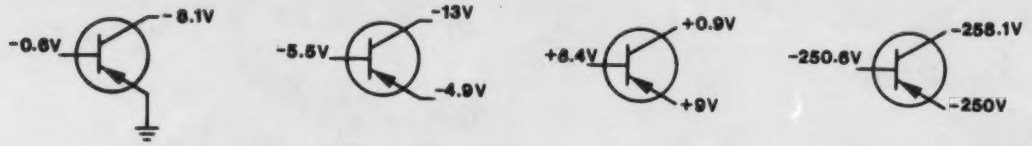


Figure 2

Again, use the emitter as a reference point. In a PNP transistor biased for conduction, the base will be more negative than the emitter and the collector will be more negative than the base and the emitter.

The type of transistor shown in Figure 2 has these voltage requirements; collector 8.1 volts more negative than the emitter, the base is .6 volts more negative than the emitter. Again, many different voltages and polarities can meet this transistor's voltage requirements.

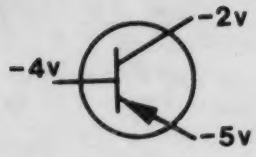
In a PNP transistor correctly biased for conduction the emitter will have the (most/least) negative potential applied to it.

- - - -

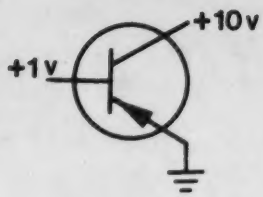
6. TEST FRAME

Which of the following PNP transistors will conduct with the given static bias voltages?

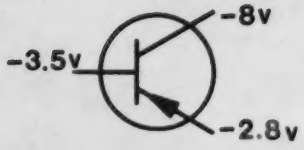
a.



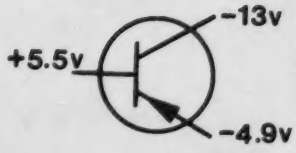
c.



b.



d.



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(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER AT THE TOP OF THE NEXT PAGE.)

b. _____

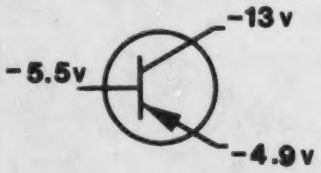
IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 12. OTHERWISE, GO BACK TO FRAME 4 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 6 AGAIN.

7. Measuring the voltage potential on any lead of a PNP transistor is done the same way as with the NPN transistor; from the transistor's lead to ground. Also to determine a static bias voltage for a PNP transistor you subtract one lead voltage from another. For example:

Vcollector = -13V

Vbase = -5.5V

Vemitter = -4.9V

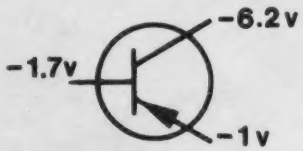


Base-Emitter static bias voltage (Vbe) = Vbase - Vemitter
= -5.5V - (-4.9V)
= -5.5V + 4.9V
= -.6V

Collector-Emitter static bias voltage (Vce) = Vcollector - Vemitter
= -13V - (-4.9V)
= -13V +4.9V
= -8.1V

To insure the proper polarity of Vbe or Vce you must remember to always subtract the emitter voltage from the base or collector voltage exactly as you did with the NPN transistor.

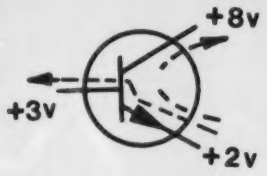
For the following transistor the static bias voltages are;
Base-Emitter (Vbe) = _____, Collector-Emitter (Vce) = _____.



- -

Vbe = -.7V, Vce = -5.2V

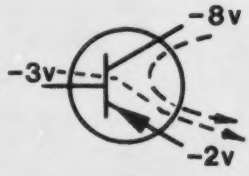
8. Notice that for both the NPN and PNP transistors current flows against the arrow the same as was true for a diode. Current will flow from the emitter to the collector and the base in the NPN transistor. See Figure 3.



NPN Transistor Current

Figure 3

Current flows from the collector and the base to the emitter in the PNP transistor. See Figure 4.



PNP Transistor Current

Figure 4

Because of transistor construction, current will not flow from base to collector or collector to base. The majority of the current flows in the emitter-collector circuit with a small amount of current in the base-emitter circuit.

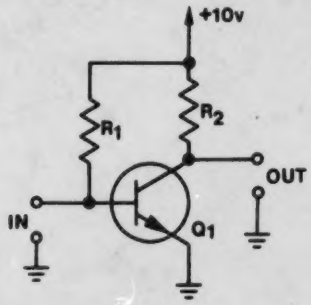
The emitter current in either the NPN or PNP transistor is the

a. collector current minus the base current.
b. base current.
c. collector current plus the base current.
d. collector current.

- -

c. collector current plus the base current.

9. We have been discussing static bias voltages and polarities. Now let's look at the transistor in a circuit to see where the voltages are actually coming from. See Figure 5.



NPN Transistor Circuit

Figure 5

The voltage applied to the collector-emitter circuit comes from the +10 volt source voltage through R2. The voltage at the base-emitter is a little more involved.

R1 and the base-emitter form a voltage divider. Current flows from ground through Q1's base-emitter, through R1 to the supply voltage, called "Vcc", or in this case, +10 volts. The emitter-base has a certain amount of fixed resistance which will develop a voltage drop. This voltage is dependent on the supply voltage and the amount of current R1 allows to flow. Therefore, by choosing different values of supply voltage and R1, we can set different values of static bias voltage on the base of Q1. Normally R1 is used to set Q1's base voltage as one supply voltage is supplying a number of circuits.

In the circuit in Figure 6, as R1's resistance is increased the emitter-base current (increases/decreases) which causes the base static bias voltage to (increase/decrease).

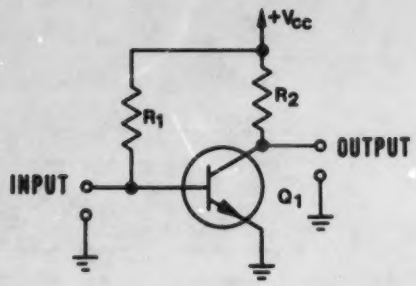


Figure 6

- -

decreases,decrease (in that order)

10. Without a way to control the current flow through a transistor, the transistor would be a useless device. However, we do control current flow with the transistor's base.

The base of a transistor can be compared to the valve on a water pipe. The base controls electron flow in the collector-emitter circuit just as the valve controls the flow of water in a pipe. Because of transistor construction, the base requires only a very small voltage, a few tenths of a volt on the base-emitter to control collector-emitter conduction. An increase in positive (or decrease in negative) voltage on the base of an NPN transistor increases the collector-emitter conduction. A decrease in positive (or increase in negative) voltage will decrease conduction.

The same is true of the PNP transistor, only the voltage polarities are reversed. An increase in negative (or decrease in positive) on the base of a PNP transistor increases the collector-emitter conduction. A decrease in negative (or increase in positive) voltage will decrease conduction.

In other words, for either transistor type, increasing the forward bias on the base-emitter will increase collector-emitter conduction. A decrease in forward bias on the base-emitter will decrease collector-emitter conduction.

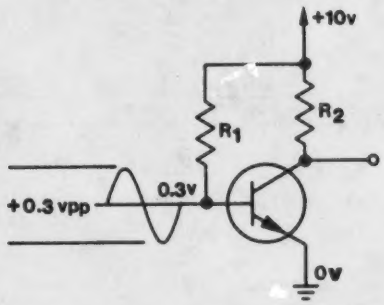
Which lead has the most control of electron flow for a three element transistor?

a. Collector
b. Emitter
c. Base

- -

c. Base

11. Take a look at Figure 7.



NPN Transistor Circuit with Input Signal

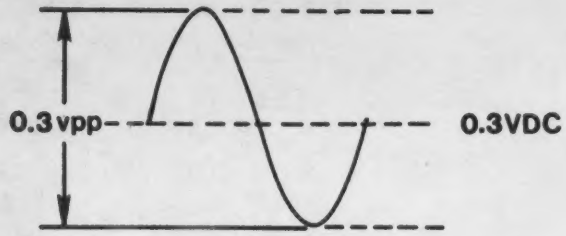
Figure 7

The collector is biased at +10 volts, the base is static biased at 0.3 volts, and the emitter is at ground potential. The sine wave applied to the base has a 0.3 volt peak-to-peak amplitude.

The sine wave begins its positive swing. When the sine wave reaches its peak, the potential on the base will be +0.45 volts. This new bias potential is termed Dynamic Bias. Dynamic bias is the bias voltage on the base of a transistor with a signal applied and will be a combination of the static bias voltage and the input signal. This voltage will change with the input signal.

At the peak positive swing of the input signal the base will be more positive with respect to ground and the emitter, which causes an increase in transistor conductivity. When transistor conductivity increases its emitter-collector resistance decreases causing a decrease in the voltage dropped across the transistor. The increase in conduction will increase the voltage drop across R2.

What dynamic bias potential will be on the base when the sine wave reaches its peak negative variation?



a. -0.45 VDC
b. +0.15 VDC
c. -0.15 VDC
d. 0.00 VDC

- -

b. +0.15 VDC

12. TEST FRAME

Which statement best describes the action on an NPN transistor when the input sine wave reaches its peak negative variation?

a. Conductivity has decreased and voltage across the transistor has decreased.
b. Conductivity has increased and voltage across the transistor has increased.
c. Conductivity has decreased and voltage across the transistor has increased.
d. Conductivity has increased and voltage across the transistor has decreased.

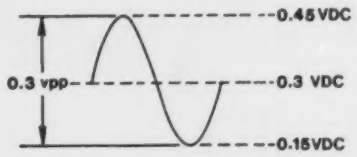
- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER AT THE TOP OF THE NEXT PAGE.)

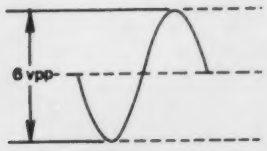
c. Voltage across the transistor has increased and conductivity has decreased.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 15. OTHERWISE, GO BACK TO FRAME 7 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

13. The conductivity of the NPN transistor increases on the positive variation. With this signal in,



we will get this signal out.



No, it's not magic! It's amplification and inversion. Let's take a closer look at what's happening to the signal. See Figure 8.

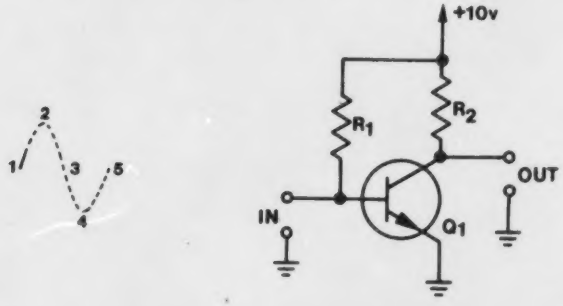


Figure 8

At Time 1 the sine wave starts to increase, causing the potential on the base to increase, which causes transistor conduction to increase, and the voltage across the transistor to decrease.

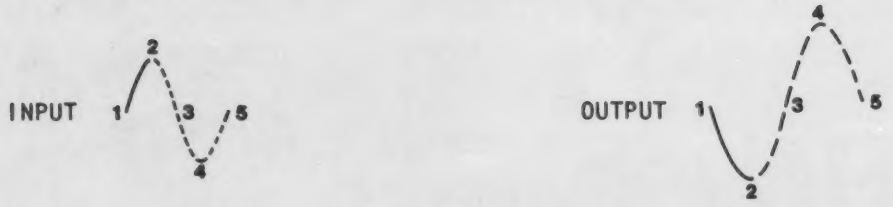


Figure 9

In Figure 9, at Time 2 the sine wave has reached its peak positive variation and transistor conduction is maximum, but voltage across the transistor is minimum.

From Time 2 to Time 4 in Figure 10, the sine wave is going from its peak positive variation to its peak negative variation (or from +0.45 V to +0.15 V).

Figure 10

The transistor will go from maximum conduction to minimum conduction (at Time 4) and the voltage across the transistor will go from minimum at the positive peak to maximum at the negative peak (Time 4), with the waveform in Figure 11 at the output.

Figure 11

180° phase reversed will always occur when the output is taken from the collector with the input applied to the base regardless of which type of transistor is used.

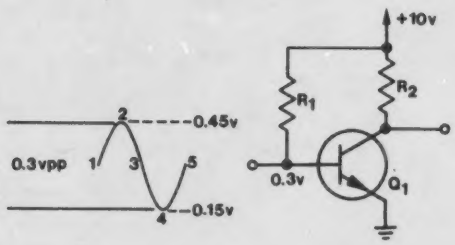
At Time 5 the sine wave has completed its cycle (Figure 12),

Figure 12

and the signal at the output has been amplified and inverted (Figure 13).

Figure 13

In Figure 14, the sine wave is being injected on the base of an NPN transistor. At Time 4 the transistor's:



a. Conduction is maximum.
b. Conduction is minimum.
c. Conduction is increasing.
d. Conduction is decreasing.

Figure 14

- -

b. Conduction is minimum.

14. The relatively high voltage supplied for the collector is referred to as "Vcc". Vcc is an abbreviation for collector supply voltage. No matter how much the transistor amplifies a signal, the "p-p" output cannot exceed the value of Vcc. In other words, if Vcc is +10 volts or -10 volts (depending on the type of transistor) the largest signal you can have at the collector is 10 volts peak-to-peak. The transistor can amplify but it cannot create extra voltage.

TRUE or FALSE

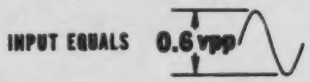
With an 8V Vcc the maximum output voltage of a transistor amplifier is 16V P-P.

- -

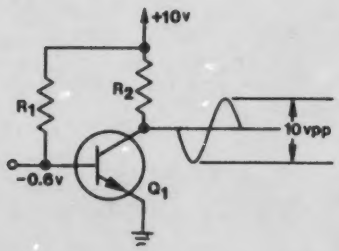
FALSE: The peak-to-peak output can NOT exceed Vcc.

15. TEST FRAME

Which of the following illustrations is correct?



a.



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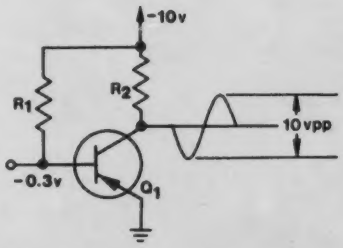
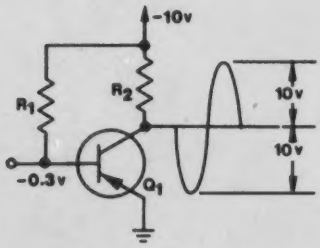
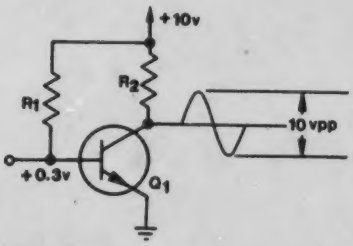


c.



d.



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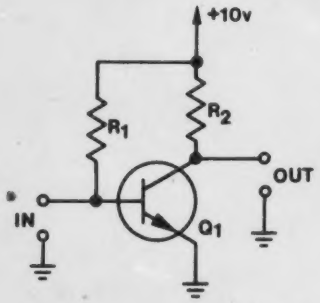
(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

b.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 19 OTHERWISE, GO BACK TO FRAME 13 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 15 AGAIN.

16. Transistors are rugged devices, but there is one thing that will easily destroy them...heat. For this reason transistorized equipment will usually be located in air conditioned spaces. However, the transistor itself can create conditions that will cause it to overheat.

A transistor is actually a current control device. A small current flow in the base-emitter circuit controls a large current flow in the collector-emitter circuit. (The reason we use bias voltage readings is that voltage is more convenient to measure than current.) Increasing base-emitter current will increase collector-emitter current. Likewise, a decrease in base-emitter current will decrease collector-emitter current. This is true for both NPN and PNP transistors. When fixed base bias is used, as shown in Figure 15, the only control over static current flow in the base-emitter circuit is junction resistance and R1's resistance.

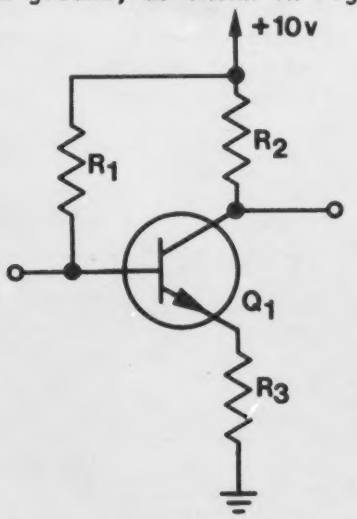


Fixed Base Bias Circuit

Figure 15

R1's resistance is a fixed value and will not change. However, one property of a transistor is that when it exceeds a certain temperature, base-emitter resistance begins to decrease. This allows more current to flow through the base-emitter which would increase conduction in the collector-emitter circuit. An increase in current through the transistor increases the amount of heat produced internally. The higher heat further reduces the base-emitter resistance increasing transistor conduction and again producing more heat. Once started, this process, called thermal runaway, continues until the transistor destroys itself.

There are a few methods of stopping thermal runaway, the most common method being a stabilizing resistor, called an emitter resistor, placed between the emitter and ground, as shown in Figure 16.



NPN Transistor Circuit with Emitter Resistor

Figure 16

R3 is placed between ground and the emitter. Its resistance will be large as compared to the base-emitter resistance. Now if the base-emitter resistance decreases from heat, there will be practically no change in current flow as base-emitter resistance has become only a small percentage of the total base-emitter circuit resistance. For example, a transistor has a base-emitter resistance of 10Ω and an emitter resistor of 1000Ω. With a base bias voltage of .5 volts the base-emitter current will be $\frac{.5v}{1010\Omega}$ = .4950ma.

If base-emitter resistance decreases to 9Ω from heating up, base-emitter current increases to $\frac{.5v}{1009\Omega}$ = .4955 ma.

The increase in base-emitter current, .0005ma., will have no noticeable effect on the transistor.

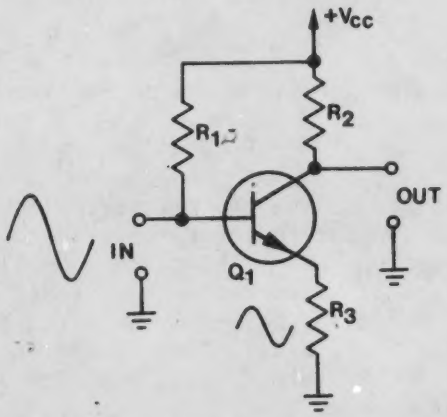
The emitter resistor prevents thermal runaway by

a. decreasing the base-emitter resistance.
b. causing the base-emitter resistance to become a large percentage of the total base-emitter circuit resistance.
c. increasing the base-emitter resistance.
d. causing the base-emitter resistance to become only a small percentage of the total base-emitter circuit resistance.

- -

d. causing the base-emitter resistance to become only a small percentage of the total base-emitter circuit resistance.

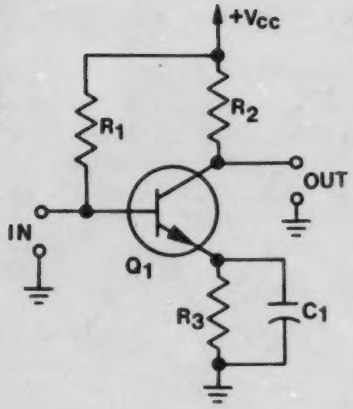
17. The emitter resistor helps cure thermal runaway, but creates a problem. Refer to Figure 17.



Degenerating Signal on Emitter Resistor

Figure 17

When a signal is applied to the transistor's base an in-phase version of the input signal is developed across R3, the emitter resistor. This signal causes Q1's emitter voltage to vary in-phase with the input signal. Since a transistor must have a difference in potential between base and emitter to change its collector-emitter conduction and the emitter voltage is now varying by almost the same amount and in-phase with the input signal, the potential difference is reduced. This causes degeneration (a reduction in amplification). This is an undesirable effect, but is curable. Take a look at Figure 18.



NPN Transistor Circuit with Emitter Resistor and Emitter By-Pass Capacitor

Figure 18

A capacitor has been added to the circuit. It is commonly called an emitter by-pass capacitor. While it has no effect on static bias conditions, it shunts (or by-passes) to ground the signal variations that would have been developed across the emitter resistor and prevents degeneration.

The emitter by-pass capacitor's function is to _____.

- -

Shunt signal variations around the emitter resistor to ground to prevent degeneration while allowing the emitter resistor to prevent thermal runaway. (Or words to that effect)

18. There is one other cause of thermal runaway that does not always occur as it is dependent on circuit design. In some circuits it is possible for the transistor's base to build up a charge. This charge is positive in an NPN transistor and negative in a PNP transistor. In either case (NPN or PNP) forward bias is increased by this charge. When forward bias increases, transistor conduction increases. Heat is produced by the increased conduction which increases the charge on the base, increasing forward bias even more. This cycle continues until the transistor is destroyed by heat. Thermal runaway has again occured. To bleed off this charge as it forms, a resistor is placed between the transistor's base and ground, as is shown in Figure 19.

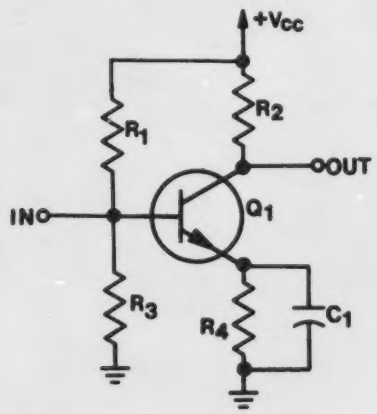


Figure 19

R3 will bleed off the excess charge with very little effect on the static base bias voltage, again stabilizing the transistor.

A resistor placed between a transistor's base and ground (can/can not) help prevent thermal runaway.

- -

can

19. TEST FRAME

Referring to Figure 20, match the function in column B to its component in column A. (Choices from column B may be used more than once.)

Column A	Column B
1. R3	a. prevents thermal runaway
2. C1	b. prevents degeneration
3. R4	

a. 1. b; 2. a; 3. b
b. 1. a; 2. b; 3. b
c. 1. b; 2. a; 3. a
d. 1. a; 2. b; 3. a

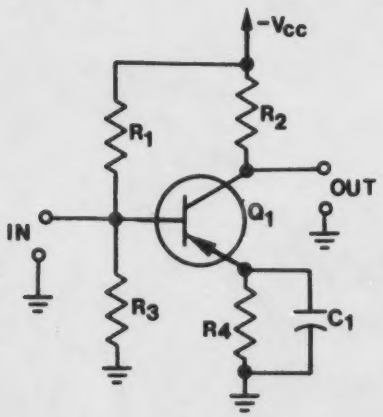


Figure 20

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER AT THE TOP OF THE NEXT PAGE.)

d. 1. a; 2. b; 3. a

IF YOUR ANSWER MATCHES THE CORRECT ANSWER YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON II MODULE TWENTY ONE. OTHERWISE, GO BACK TO FRAME 16 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 19 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

NARRATIVE
LESSON II

Transistor Biasing

You know that there are two types of transistors (NPN and PNP) and that both types can amplify signals. However, just as a car will not function properly unless a certain set of conditions is met, a transistor will not function properly unless its set of conditions is met. The majority of the transistor's operating conditions come under the heading of Static Bias.

Static bias is defined as the DC potentials at the collector and base with respect to the emitter necessary to establish a transistor's conduction level.

You must remember to think of the transistor's emitter as a reference point. In an NPN transistor biased for conduction, the base will be more positive than the emitter, and the collector will be more positive than the base and emitter. This is shown in Figure 1.

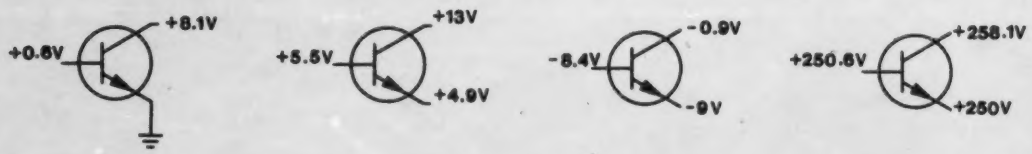


Figure 1

The transistor shown in Figure 1 has these voltage requirements; the collector is 8.1 volts more positive than the emitter, the base is .6 volts more positive than the emitter. As you can see from Figure 1, many different voltages and polarities can meet this transistor's voltage requirements.

The direction of current flow in a PNP transistor is the reverse of the NPN's current flow. Thus, in the PNP transistor, biased for conduction, the base will be more negative than the emitter, and the collector will be more negative than the base and emitter, as shown in Figure 2.

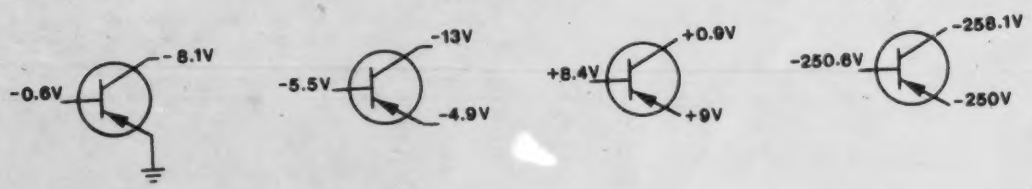
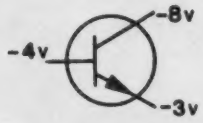


Figure 2

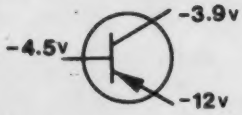
In Figure 2, again using the emitter as a reference point, the transistor's voltage requirements are; the base is .6 volts more negative than the emitter, the collector is 8.1 volts more negative than the emitter. Again, these voltage requirements were met with a number of different voltages and polarities.

Which of the following transistors have the correct static bias potentials applied for conduction? (There may be more than one correct choice.)

a.

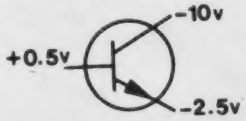


b.

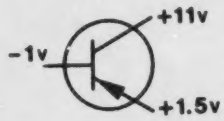


c.

d.



e.



f.

- -

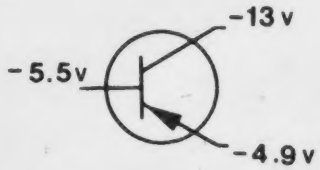
c., f.

The voltages present on each of the transistor's leads are usually measured and shown on a schematic using ground as a reference. However, the actual static bias voltage that establishes the transistor's conduction level is the voltage on the base and collector with the emitter used as a reference. These voltages appear across pairs of a transistor's elements, base-emitter being one pair and collector-emitter being the other pair. The collector-emitter static bias voltage (Vce) and base-emitter static bias voltage (Vbe) are found by subtracting the emitter voltage from the collector voltage for Vce, or the base voltage for Vbe. See Figure 3.

Vcollector = -13V

Vbase = -5.5V

Vemitter = -4.9V



Base-Emitter static bias voltage (Vbe) = Vbase - Vemitter
= -5.5V - (-4.9V)
= -5.5V + 4.9V
= -.6V

Collector-Emitter static bias voltage (Vce) = Vcollector - Vemitter
= -13V - (-4.9V)
= -13V + 4.9V
= -8.1V

Figuring Vbe and Vce for PNP Transistors

Figure 3

Regardless of the type of transistor (NPN or PNP), the correct polarities and voltages of the static bias are obtained by subtracting the emitter voltage from the base or collector voltage.

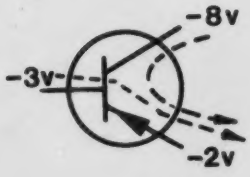
Referring to Figure 4, the static bias voltages are: Base-Emitter (Vbe) = _____, Collector-Emitter (Vce) = _____.

Figure 4

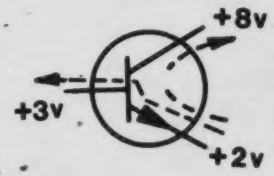
- -

+.7V, +5.2V (In that order.)

Current flow in both the PNP and NPN transistors is against the arrows as shown in Figure 5.



PNP



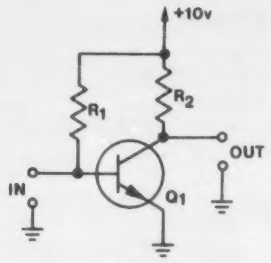
NPN

Transistor Current Flow

Figure 5

Notice that in both cases the emitter current is the combination of the base and collector currents. The majority of the current flow will be in the emitter-collector circuit with a small current flow in the base-emitter circuit. Because of transistor construction there will be no current flow between the base and collector.

By now you may be wondering where the transistor's operating voltages are coming from. Take a look at Figure 6.



NPN Transistor Circuit

Figure 6

The voltage applied to collector-emitter comes from the +10 volt supply through R2. The voltage on base-emitter is a little more involved.

R1 and base-emitter form a voltage divider. Current flows from ground through Q1's base-emitter, through R1 to the supply voltage, called "Vcc", which in this case is +10 volts. The base-emitter has a certain fixed resistance which develops a voltage drop. The amount of voltage dropped will be dependent on the supply voltage and the amount of current R1 allows to flow. The supply voltage is not normally varied to change the static bias voltage on the transistor's base as it is usually a fixed value. However, by choosing different values of R1 we can easily set different values of static bias voltage on the base of Q1.

Referring to Figure 7, as R1's resistance is decreased the base-emitter current (increases/decreases) which (increases/decreases) the base static bias voltage.

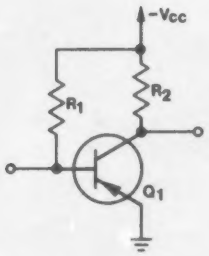


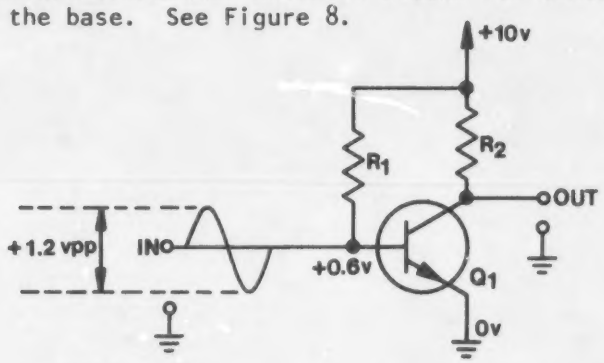
Figure 7

- -

increases, increases

The base-emitter static bias voltage (Vbe) is an important parameter. This is because the transistor's base is its control lead. The base can be compared to the valve on a water pipe. The valve controls the flow of water through the pipe. The base controls the flow of electrons through the collector-emitter circuit. The amount of collector-emitter current the base allows to flow is determined by the voltage on the base with respect to the emitter. Because of transistor construction, the base requires only a very small voltage, a few tenths of a volt on base-emitter to control collector-emitter conduction.

Let's look at an NPN transistor which is biased for conduction and inject a sine wave at the base. See Figure 8.



NPN Transistor Circuit with Input Signal

Figure 8

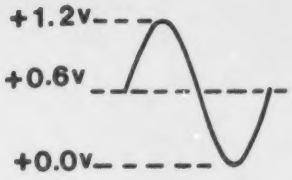
The sine wave injected at the base of the transistor will cause the transistor's conductivity to increase and decrease. The transistor's conductivity will increase during the positive excursion of the sine wave and decrease during the negative excursion.

Take a look at Figure 8. The collector supply is +10 volts DC. The base is +0.6 volts DC and the emitter is at ground (reference).

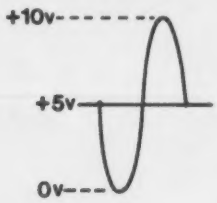
A 1.2 volt peak-to-peak sine wave is being applied to the base. When the sine wave reaches its maximum positive swing the potential on the base will be +1.2 volts DC as shown in the following illustration. This new base bias potential is Dynamic Bias. Dynamic bias is the bias voltage on the base of a transistor with a signal applied and is a combination of the input signal and the static bias voltage. This voltage will change with the input signal.

70

Transistor conductivity is maximum but the voltage across the transistor, collector to emitter, is minimum (the load resistor R2 will drop most of the voltage). On the oscilloscope you will see this input at the base



and this output at the collector.

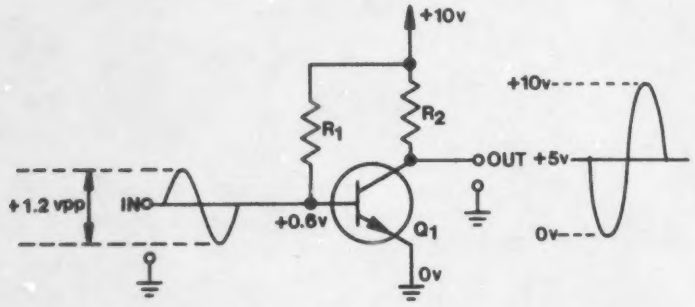


Magic? No! The oscilloscope shows only voltage and since the voltage across the transistor is decreasing you'll see a negative-going, amplified (larger) output at the collector.

On the negative swing of the input sine wave the opposite occurs. At the peak of the negative swing, the input voltage goes down to 0.0 volts which causes the conductivity of the transistor to decrease and the voltage across the transistor to increase. Again, we only see voltage on an oscilloscope so the negative (or less positive) variation will cause an amplified, positive-going output at the collector.

This 180° phase reversal will always occur when the output is taken from the collector with the input applied to the base regardless of whether the transistor is NPN or PNP.

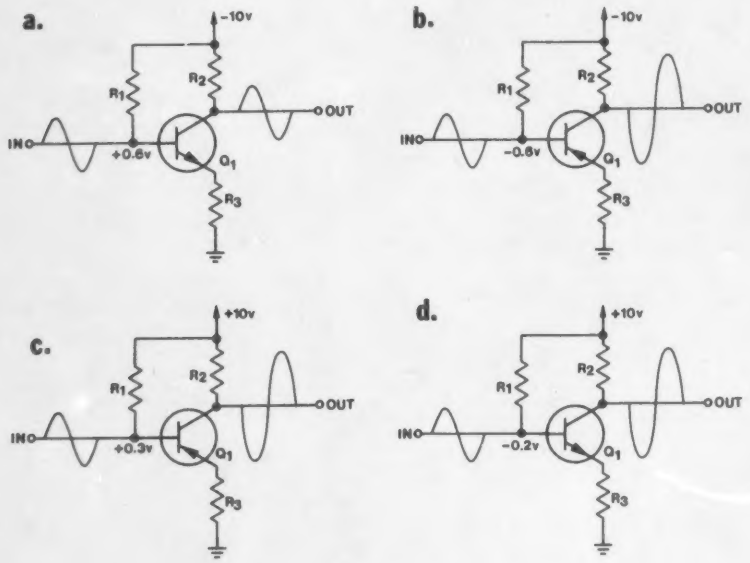
You know that transistors are current amplifying devices. You also know the conditions necessary to properly bias the transistor. The relatively high voltage supplied for the collector is referred to as Vcc (collector supply voltage). No matter how much the transistor amplifies a signal, the peak-to-peak output cannot exceed the value of Vcc. In other words, if Vcc is +10 volts or -10 volts, depending on the type of transistor used, the largest signal you can have at the collector is 10 volts peak-to-peak. The transistor can amplify, but it cannot create extra voltage. See Figure 9.



NPN Transistor Circuit with Input and Output Signals

Figure 9

Which one of the following illustrations is correct?



b.

Transistors are rugged, but there is one thing that can easily destroy them... heat. Transistorized equipment will usually be located in an air conditioned space which will help minimize heat-related problems. However, the transistor itself can create conditions that will cause it to overheat.

Although we use voltage readings for bias measurement (voltage being much easier to measure than current) it is current that controls the transistor's conduction. A small current flow through base-emitter controls a large current flow in the collector-emitter circuit. Increasing base-emitter current increases collector-emitter current. Decreasing base-emitter current decreases collector-emitter current. This is true for both NPN and PNP transistors. With the type of circuit we have been discussing, called a fixed bias amplifier, see Figure 10, the only control over static current flow in the base-emitter circuit is the base-emitter resistance and R1's resistance.

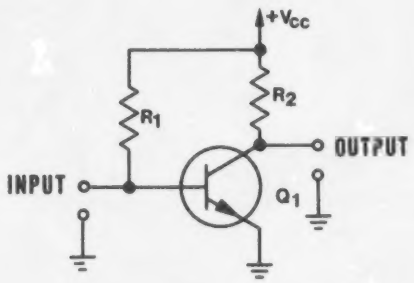
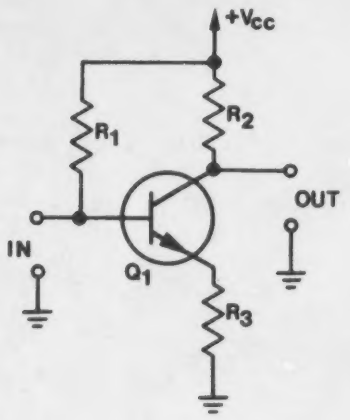


Figure 10

R1's resistance is fixed, but Q1's base-emitter resistance will begin to decrease when the base-emitter exceeds a certain temperature limit. This allows more current to flow through the base-emitter, increasing collector-emitter current flow. The increase in collector-emitter current produces more internal heating of the transistor. The increase in heat increases conduction which produces even more heat. Once started, this process, called thermal runaway, continues until the transistor destroys itself.

One common method of stabilizing the transistor against thermal runaway is by placing a resistor, called an emitter resistor, between a transistor's emitter and ground, as shown in Figure 11.



NPN Transistor Circuit with Emitter Resistor

Figure 11

R3, the emitter resistor, has a large resistance as compared to the base-emitter resistance. Now, the base-emitter resistance is only a small percentage of the total base-emitter circuit resistance. If the base-emitter resistance decreases from heat there will be practically no change in junction current flow and thermal runaway will not occur. For example, a transistor has a base-emitter resistance of 10 Ω and an emitter resistor of 1000Ω. With a base bias voltage of .5V the base-emitter current will be

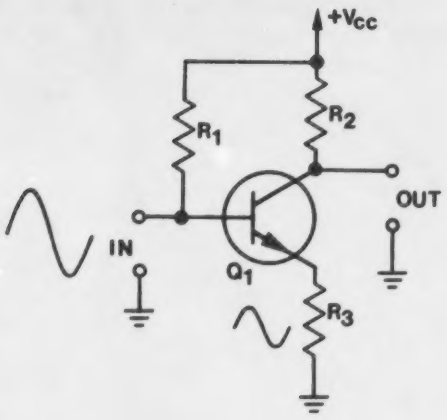
$$\frac{.5\text{volts}}{1010\Omega} = .4950 \text{ ma.}$$

If base-emitter resistance decreases to 9Ω from heating up, base-emitter current increases to

$$\frac{.5\text{volts}}{1009\Omega} = .4955 \text{ ma.}$$

The increase in base-emitter current, .0005 ma., will have no noticeable effect on transistor conduction, and the transistor is stabilized against thermal runaway.

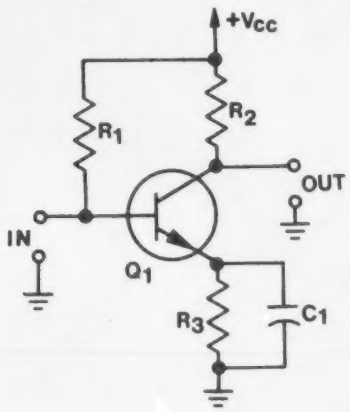
The emitter resistor helps cure thermal runaway, but causes another problem. Refer to Figure 12.



Degenerating Signal Developed by Emitter Resistor

Figure 12

When a signal is applied to Q1's base an in-phase version of the input signal is developed across R3, the emitter resistor. This signal causes Q1's emitter voltage to vary in-phase with the input signal. Since a transistor must have a difference in potential between base and emitter to change its collector-emitter conduction and the emitter voltage is now varying by almost the same amount and in-phase with the input signal, the potential difference is reduced. This causes degeneration (a reduction in amplification). This effect is undesirable, but curable. Take a look at Figure 13.



NPN Transistor Circuit with Emitter Resistor and Emitter By-Pass Capacitor

Figure 13

A capacitor, commonly called an emitter by-pass capacitor, has been added. While it has no effect on static bias conditions, it shunts (by-passes) any signals developed across the emitter resistor to ground thereby preventing degeneration.

We have discussed one cause of thermal runaway and how it is cured. There is one other cause of thermal runaway which does not always occur as it depends on circuit design and usage.

In some circuits it is possible for the transistor's base to build up a charge, positive for NPN and negative for PNP. In either case (NPN or PNP) this charge increases the transistor's forward bias. When forward bias increases, transistor conduction increases. This increased conduction produces heat which increases the charge even more. This cycle continues and we again have thermal runaway. To bleed off this charge as it forms, a resistor is placed between the transistor's base and ground. See Figure 14.

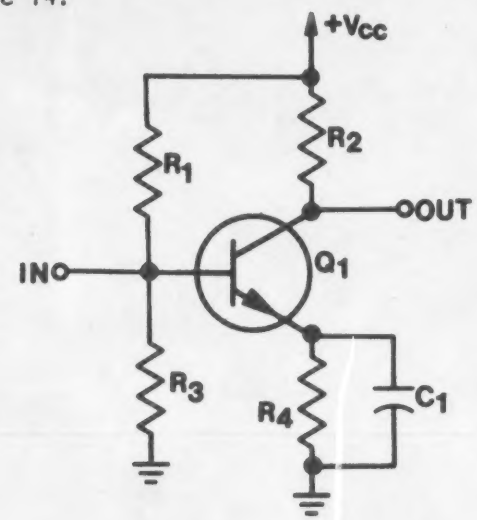


Figure 14

R3 will bleed off the charge that forms on the base of Q1 with very little effect on the base bias voltage, stabilizing the transistor.

Referring to Figure 15, R3 and R4 prevent _____ and C1 prevents _____.

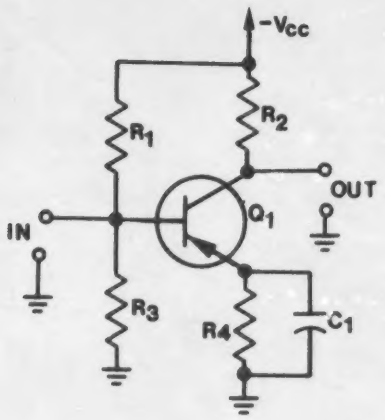


Figure 15

- -

thermal runaway, degeneration (in that order)

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE

LESSON III

Basic Transistor Amplifier Functional Analysis

1 April 1977

OVERVIEW
LESSON III

Basic Transistor Amplifier Functional Analysis

In this lesson you will learn how various components, when assembled together, form an amplifier circuit and what the function of this amplifier is. The amplifier will be broken down into three stages: input: conversion; and output. Each stage will be discussed in terms of its function.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21.3.42 When the student completes this course, he will be able to TROUBLESHOOT an audio amplifier training device, given the required test equipment, schematic diagram, and a prefaulted audio amplifier. Faults to be limited to open or shorted components; no more than one fault per problem. Remove/replace a similar component on a practice card. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21.3.42.2 IDENTIFY and locate the input section components on the basic audio amplifier training device, given a training device, technical manual or schematic diagram, and the required equipment.

21.3.42.4 DEFINE the function of an amplifier by choosing the correct statement from a list of four choices. 100% accuracy is required.

21.3.42.4.1 DEFINE the functions of each section (input, conversion, and output) of an audio frequency amplifier by selecting all of the correct statements for each from a list including (1) blocking D. C., (2) amplification, and (3) coupling. 100% accuracy is required.

21.3.42.5 DESCRIBE the major differences between R-C and transformer coupling by selecting the correct statement when given four statements comparing R-C and transformer coupling. Only one statement is completely correct. 100% accuracy is required.

21.3.42.6 DETERMINE, using the gain formula, the current gain ratio of an amplifier, given an amplifier's input and output current value. 100% accuracy is required.

OVERVIEW

21.3.42.7 LOCATE, physically and schematically, the output section and test point(s) of an audio amplifier and MEASURE the output signal voltage given an audio amplifier circuit or printed circuit board, a technical manual or schematic diagram, and a multimeter or oscilloscope. Locate applicable test points with 100% accuracy and measure the output signal voltage within ± 10%.

21.3.42.8 LOCATE, physically and schematically, the conversion and test point(s) of a basic audio amplifier and MEASURE the output signal voltage given an audio amplifier circuit or printed circuit board, a technical manual or schematic diagram, and a multimeter or oscilloscope. Locate all test points with 100% accuracy and measure the output signal voltage within ± 10%.

21.3.42.9 LOCATE a faulty conversion section component in a basic audio amplifier, given a technical manual (or schematic), a circuit or circuit board containing at least one amplifier stage, a multimeter, signal generator, and an oscilloscope. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON III

Basic Transistor Amplifier Functional Analysis

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Narrative

Student's Guide:

Job Program Twenty One-III "Basic Transistor Amplifier Analysis"
Progress Check

Enrichment Material(s):

Electronics Installation and Maintenance Book, Electronic Circuits, NAVSHIPS 0967-000-0120, section 5
Basic Electronics, Vol. 1, NAVPERS 10087-C

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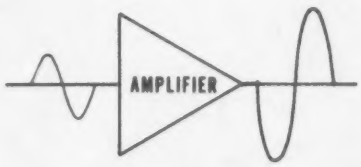
SUMMARY
LESSON III

Basic Transistor Amplifier Functional Analysis

In transistorized equipment you will come across amplifiers. The function of an amplifier is to amplify a signal; that is, make it larger. Each amplifier stage will have a certain amount of gain. The stage will provide a specific amount of amplification for any input signal within the amplifiers limits. Gain is the ratio of the amplitude of the output signal to the amplitude of the input signal.

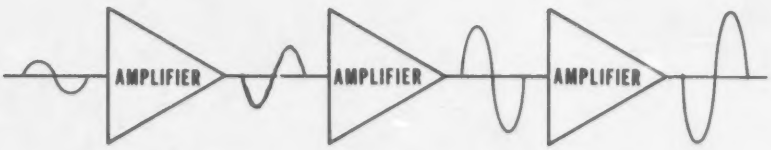
Amplifiers can be broken down into three sections. Input, output, and conversion. The input and output sections have the same function. They couple the signal to and from the amplifier stage and also block DC from the previous or following stage. Remember, capacitors and transformers can couple AC while blocking DC. The conversion section is the heart of the amplifier stage. In the single-ended type amplifier (one input and one output), the conversion section is the transistor. A small signal applied to the base of the transistor controls a larger current through the transistor.

The symbol we use to represent an amplifer is a triangle, as shown in Figure 1.



COMMON AMPLIFIER SYMBOL
Figure 1

Single-ended amplifiers connected in series are called cascade coupled. That is, the output from one amplifier is connected to the input of the next amplifier, and so on, until the desired signal strength is obtained to drive the final stage.



CASCADED AMPLIFIERS
Figure 2

There are two common types of coupling: Resistive-Capacitive (RC) and transformer. RC is the most common of the two types. The reason is that RC coupling uses smaller components that cost less and have a wider frequency response. RC couping is used for voltage amplifiers with low power output. Transformer coupling is used extensively in high power cascade coupling. Transformer coupling is accomplished through mutual induction between primary and secondary windings

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NARRATIVE
LESSON III

Basic Transistor Amplifier Functional Analysis

This lesson deals with amplification, the function of an amplifier in an electronic circuit. Amplification is the process of making a signal larger. In transistorized amplifiers, a small signal controls a relatively large current through the transistor (see Figure 1).

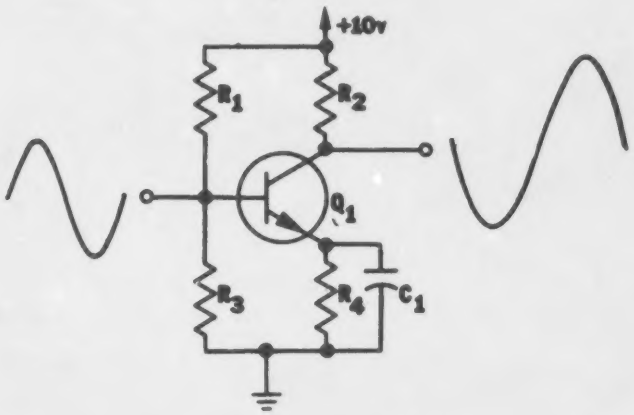


Figure 1

In your own words describe the action of an amplifier. _____
_____.

- -

_____
A small signal controls a large current through the transistor. (or words to that effect)
_____

All amplifiers have gain (the number of times the transistor will increase the input signal). Most amplifiers are designed for either voltage or current gain according to circuit requirements. For example, if the current gain of a transistor is 50, and the input signal has a change of 100 microamps (μa), the output would have a change of 5000 μa or 5 milliamps (ma). The gain is the ratio of output to input signals.

$$\text{Current Gain} = \frac{I_{out}}{I_{in}} = \frac{5000\mu a}{100\mu a} = 50$$

Most power amplifiers are current gain amplifiers. The voltage at the output is low, but the current is large.

Amplifiers can be broken down into three sections. Input, output, and conversion sections, as shown in Figure 2.

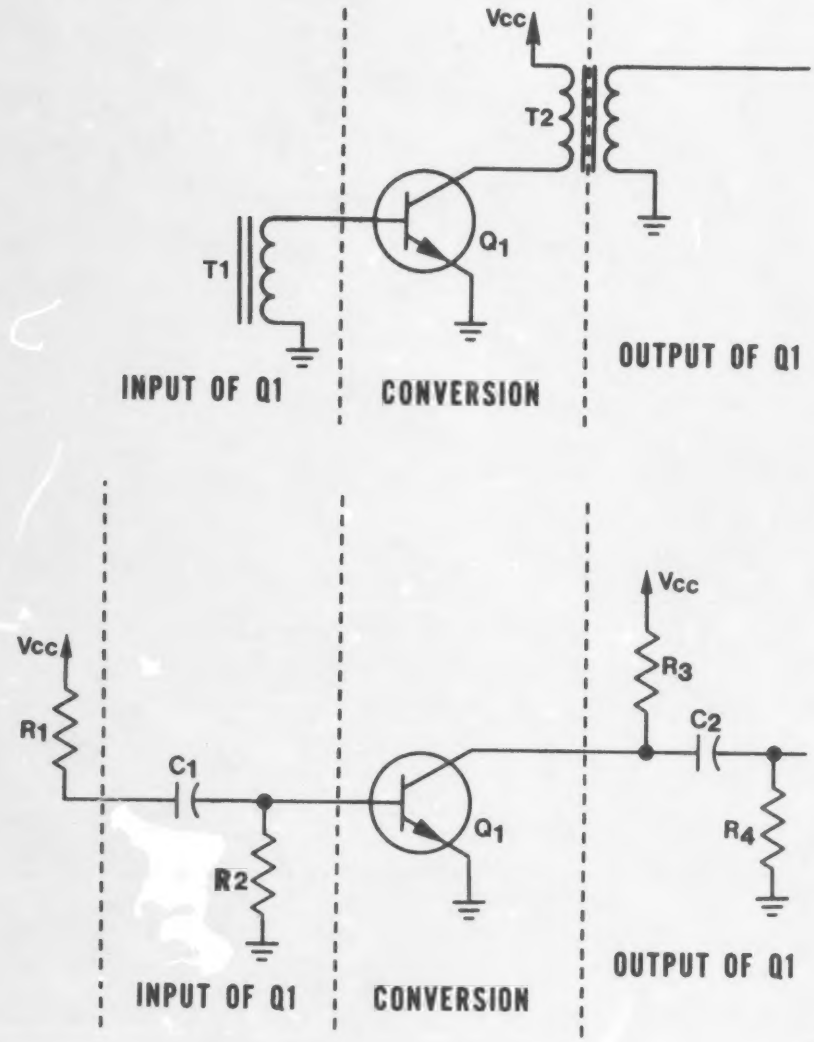


Figure 2

The input section and the output section are functionally similar. The input section couples the signal from the preceding stage to the conversion section of the amplifier. It also prevents, or blocks, DC from the previous stage from affecting this amplifier. The output section couples the amplifier signal from the conversion section to the following stage. It also blocks DC between the amplifier and the following stage.

Match the proper function(s) to the section. (Some answers may require more than one letter.)

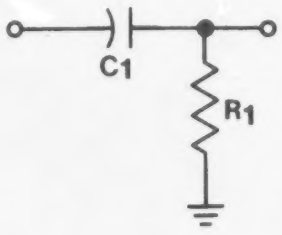
1.	Input	a.	Amplification
2.	Converison	b.	Blocks DC between stages
3.	Output	c.	Couples signal

- -

1. b, c; 2. a; 3. b, c

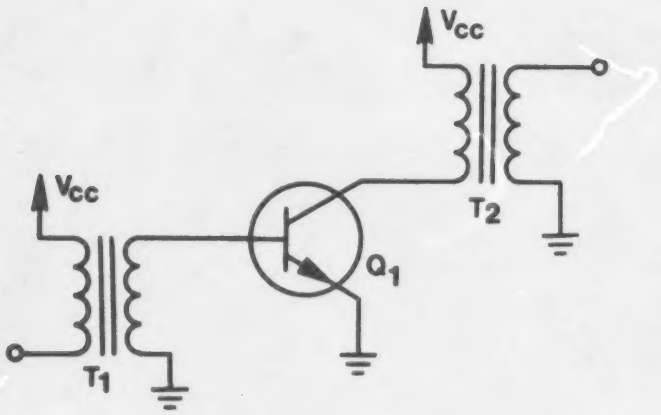
There are two methods of coupling commonly used in amplifiers. One is resistive-capacitive (RC), and the other is transformer.

RC coupling is the most common of the two types (see Figure 3). The advantages of RC coupling are small size of the components, low cost, and a wider frequency response. RC coupling is used for voltage amplifiers which have a low power output.



RC COUPLING
Figure 3

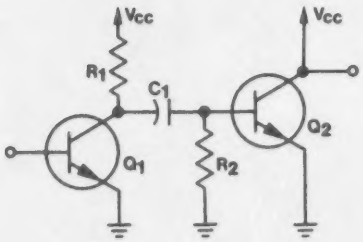
Transformer coupling provides additional gain and greater power transfer capability between stages than RC coupling. It has a smaller frequency response range than the RC network. Transformer coupling is accomplished through mutual induction between primary and secondary windings of interstage transformers (see Figure 4).

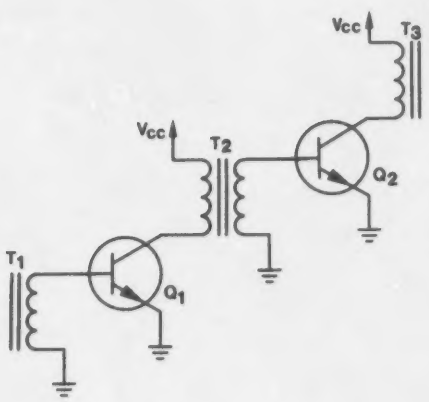


TRANSFORMER COUPLING
Figure 4

Label the two types of coupling used with the following amplifiers.

a. _____ b. _____





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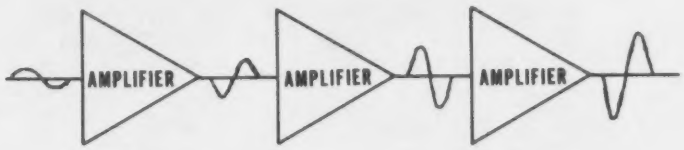
In nature, a cascade is a long stream of water flowing down a hill, pausing every so often at a ledge or pool before flowing to another stage of its journey.

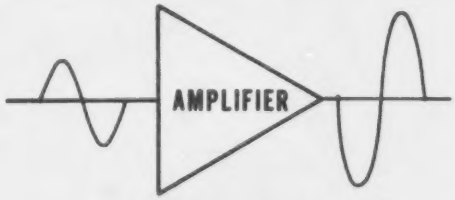
It was probably the idea of the flow through the stages of amplification that brought the term of "cascaded amplifiers."

Cascaded amplifiers are arranged so that the output of one stage is fed into the input of the next stage of amplification (Figure 5). This allows us to get much more gain than we can get from a single stage.



CASCADED AMPLIFIERS
Figure 5

What happened to the block diagram we used to use? Why a triangle! This is a common block symbol used to represent an amplifier, for it indicates the direction of signal flow, as shown in Figure 6.



COMMON AMPLIFIER SYMBOL
Figure 6

To couple different stages of cascaded amplifiers, the output impedance of one stage must be matched with the input impedance of the next; otherwise, there will be a definite loss of gain. A transistor amplifier stage can have an input impedance of 1000 ohms and an output impedance of 10,000 to 20,000 ohms. To match this high output impedance to the lower input impedance of the next stage, a matched coupling device must be used so that the conversion stage gain will not be lost. Normally, a transformer will be used for this purpose.

The conversion section is the heart of the amplifier. The simplest type of amplifier is the single-ended type; that is, an amplifier with one input and one output. In a single-ended transistor amplifier, the conversion section is the transistor. A small signal applied to the base of the transistor controls a larger current through the transistor. This is the principle of amplification and the function of the conversion section.

(1) Select the statement that best describes the function of the conversion section.

a. Removes the DC from the stage.
b. Increases the strength of the input signal.
c. Supplies DC to the output section.
d. Suppresses noise.

(2) Which statement best describes the principle of amplification in a transistor amplifier?

a. A small signal controls a large current flow.
b. A small signal increases the DC output of a transistor amplifier.
c. A large signal controls a small current flow to produce a large voltage output.
d. The input DC level controls a large current.

- -

(1) b. Increases the strength of the input signal.
(2) a. A small signal controls a large current flow.

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BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE

LESSON IV

BASIC TRANSISTOR AMPLIFIER CONFIGURATIONS

1 April 1977

OVERVIEW
LESSON IV

Basic Transistor Amplifier Configurations

In this lesson you will learn to distinguish between the three basic transistor amplifier configurations as shown in schematic representations. You will also study the functional characteristics of each configuration.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21.4.42 When the student completes this course he will be able to TROUBLESHOOT an audio amplifier training device, given the required test equipment, schematic diagram, and a prefaulted audio amplifier. Faults to be limited to open or shorted components; no more than one fault per problem. Remove/replace a similar component on a practice card. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21.4.42.14 IDENTIFY the schematic symbol, phase shift, and current gain of the common base, common collector and common emitter transistor configurations, given schematics of these configurations and a list of statements only one of which is correct. 100% accuracy is required.

21.4.42.14.1 OBSERVE the operation of the following transistor amplifiers, common emitter, common collector, and common base with regard to gain characteristics, gain, and phase inversion given a training device, an oscilloscope, and a signal generator. 100% accuracy is required.

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LIST OF STUDY RESOURCES
LESSON IV

Basic Transistor Amplifier Configurations

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Progress Check

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Basic Electronics, Vol. 1, NAVPERS 10087-C

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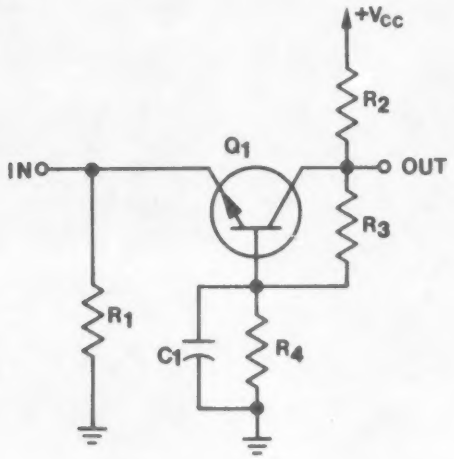
SUMMARY
LESSON IV

Basic Transistor Amplifier Configurations

Amplifiers, of one kind or another, will be encountered in practicaily every piece of electronic equipment aboard ship. The three basic transistor amplifiers can be built by using NPN or PNP transistors.

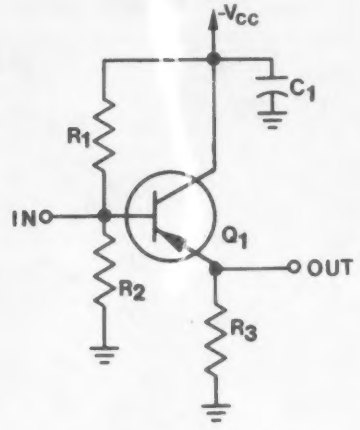
Figure 1 is a "Common Base" (CB) Amplifier.



COMMON BASE AMPLIFIER
Figure 1

The INPUT to the emitter and OUTPUT from the collector leaves the base as the common element. A high voltage gain and low current gain make the CB amplifier an ideal current control device.

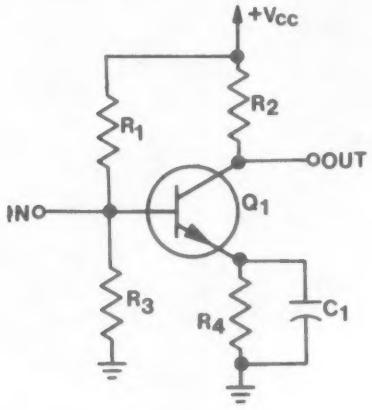
Figure 2 is a "Common Collector" (CC) amplifier.



COMMON COLLECTOR AMPLIFIER
Figure 2

The collector is the "common" element here since the input is to the base, and the output is from the emitter. High input resistance and low output resistance are the most important characteristics of this configuration since CC amplifiers are used extensively as impedance matching devices. The gain is slightly less than a 1:1 ratio.

The schematic in Figure 3 is of a typical "Common Emitter" (CE) configuration.



COMMON EMITTER AMPLIFIER
Figure 3

By observing the input and output sides of this amplifier, you can see that the emitter is the common element. Of the three types of transistor amplifiers discussed here, the CE configuration (with either the PNP or NPN transistor) is by far the most commonly used in electronics. A medium voltage and current gain provides good amplification and little distortion. The CE amplifier is the only one of the three that provides a 180° phase shift between the input and output. This condition will exist in all CE amplifiers whether an NPN or PNP transistor is used.

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NARRATIVE
LESSON IV

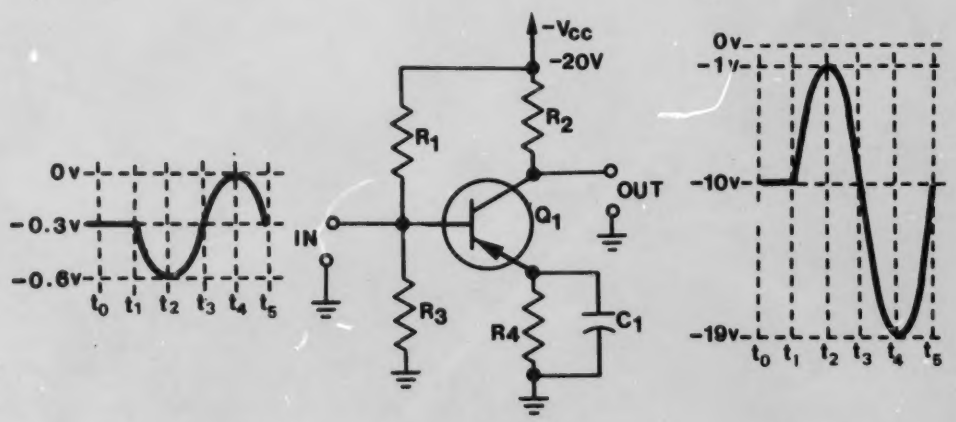
Basic Transistor Amplifier Configurations

With the advent of transistors, miniaturization of electronic circuits became practical. One of the first circuits ever miniaturized by using transistors was a simple amplifier. Pocket sized radios became a reality and since then, industry, as well as the military, has created a boom in the field of miniaturized circuitry.

This lesson deals with amplifiers in their simplest configurations. The transistors used in the amplifiers we are about to look at are the three element type (NPN/PNP) as previously discussed.

"Common Emitter" Amplifier (CE)

Up to this point we have been using common emitter (CE) amplifiers for explanation purposes. When we say common emitter we don't mean it is the most common amplifier; the common emitter amplifier (with either the PNP or NPN transistor) is the most commonly used circuit, but common emitter amplifier means the emitter is common to both the input and output. Take a look at the schematic in Figure 1.



COMMON EMITTER (CE)
Figure 1

So we can say that the lead that is neither an input nor an output is the common lead.

We know from Lesson II that we have phase inversion between the base and collector of a common emitter amplifier. This is one characteristic of the common emitter amplifier. See Figure 2.

PHASE INVERSION IN COMMON EMITTER AMPLIFIER
Figure 2

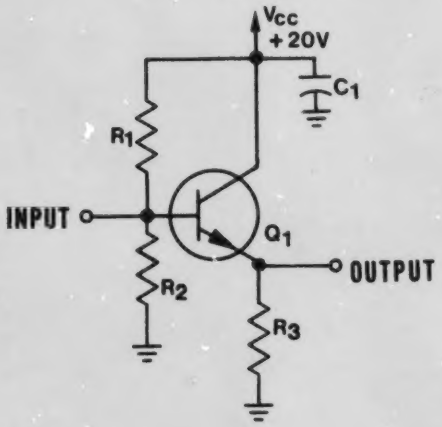
Let's quickly review common emitter amplifier operation here. At TO (in Figure 1) the circuit is in a static condition; that is, there are no signals present, only DC bias voltages. The base (input) measures -0.3V and the collector (output) has -10V DC on it. At time Tl a sine wave is applied to the base, and between times Tl and T2 the input voltage increases (in a negative direction) from -0.3V to -0.6V. This increasing base voltage causes the transistor to conduct more heavily, and that, in turn, increases the voltage dropped across R2. At time T2 the collector voltage has been reduced to -1V as shown by the output waveform. The signal inversion, then, occurs because the voltage across R2 must be subtracted from Vcc to obtain the collector voltage.

From T2 to T4 the voltage at Ql's base decreases (foreward bias in decreasing), conduction decreases, the IR drop across R2 decreases, and the output voltage rises to -19V at T4. Then from T4 to T5 the circuit returns to its starting condition.

As you may have figured out by now, we also have common base (CB) amplifiers and common collector (CC) amplifiers.

"Common Collector" Amplifier (CC)

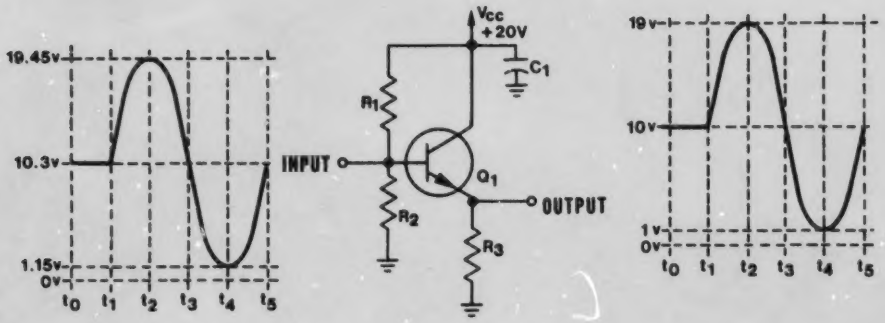
Let's take the common collector amplifiers next. Take a look at Figure 3.



COMMON COLLECTOR AMPLIFIER
Figure 3

R1 and R2 make up a voltage divider to produce bias for Q1's base. R3 is a load resistor. C1 is called a decoupling capacitor and its job is to keep the AC signals being amplified from appearing on the +Vcc supply voltage.

In a common collector amplifier, if we put an increasing positive signal in on the base of an NPN transistor we will increase conduction (reduce the resistance) of the transistor (Figure 4), so more voltage will be dropped across the series resistor.



COMMON COLLECTOR AMPLIFIER WITH INPUT AND OUTPUT SIGNALS
Figure 4

Since the output voltage is taken across this resistor, the output goes more positive.

The input goes positive and the output goes positive.

As we can see, we don't have phase inversion in a common collector amplifier. The output at the emitter is always in phase with the input at the base.

The CC amplifier is primarily used as an impedance matching device due to its high input resistance and low output resistance. For example, this type of amplifier may be used to drive a speaker directly (no transformer). The common collector gives us a low voltage gain (less than 1:1 ratio) and a high current gain. Figure 5 is a typical representation of a CC amplifier input and output relationship.

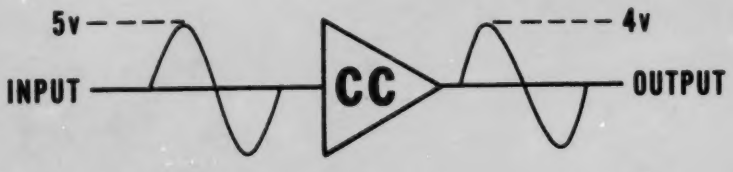
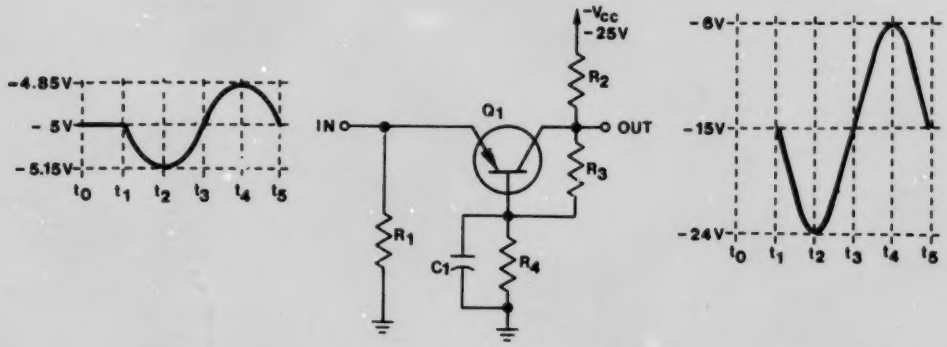


Figure 5

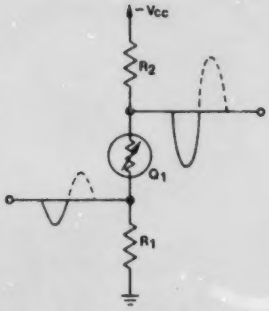
"Common Base" Amplifier (CB)

Now to common base amplifiers. Look at a basic common base amplifier (Figure 6). Notice that the input is applied to the emitter and the output is taken from the collector. In order to establish the proper bias for the transistor, this example uses a voltage divider (R3 and R4) to hold the base negative with respect to the emitter. C1 keeps any AC signals being amplified from affecting the base bias by shunting them to ground, thereby insuring the base has a non-changing negative voltage on it.



COMMON BASE AMPLIFIER
Figure 6

Resistor R2, the transistor, and R1 form a voltage divider between ground and Vcc (Figure 7).



COMMON BASE AMPLIFIER EQUIVALENT CIRCUIT
Figure 7

A negative going signal applied to the emitter of the PNP transistor will oppose forward emitter-base bias causing the resistance of the transistor to increase. With increased resistance in Q1, R2 will have a smaller voltage drop and the output will go more negative.

When the input becomes less negative it aids the forward bias of the transistor, and Q1's resistance decreases. More voltage is dropped across R2, so the output becomes less negative. The output is in phase with the input.

This amplifier can easily be used as a power supply current regulator device since the action of the transistor will oppose any voltage change felt on the emitter.

A block diagram of the common base amplifier input and output is shown in Figure 8.

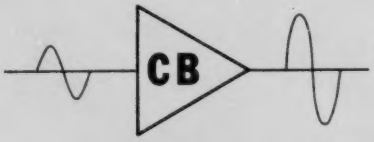
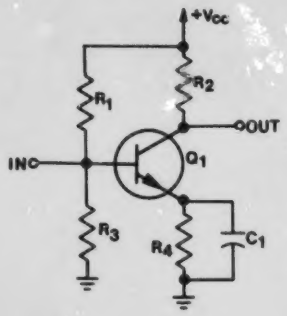


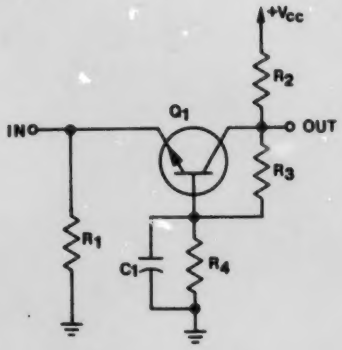
Figure 8

Label the common element of the following circuits:

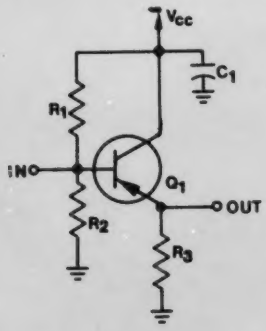
1.



2.



3.



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1. Common Emitter
2. Common Base
3. Common Collector

The following chart is provided as an easy reference for CE, CC, and CB configurations.

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
Input/Output Phase Relationship	0^0	180^0	0^0
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Medium	High	Low
Input Resistance	Low	Medium	High
Output Resistance	High	Medium	Low

Now that you have studied the various amplifier configurations, try matching the below items.

1. Provides phase inversion.
2. Used as a current control device.
3. Used as impedance matching device.
4. Most commonly used configuration.

a. CB
b. CE
c. CC

- -

1. b; 2. a; 3. c; 4. b

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE

LESSON V

BASIC TRANSISTOR AMPLIFIER CIRCUIT ANALYSIS

1 April 1977

OVERVIEW
LESSON V

Basic Transistor Amplifier Circuit Analysis

In this lesson you will learn that transistors have two limits (cutoff and saturation) that must be considered in conjunction with the operating bias to determine the class of operation a certain amplifier is designed for. You will also cover three new circuits: push-pull amplifiers; phase-splitters; and complementary-symmetry push-pull amplifiers.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21.5.42 When the student completes this course, he will be able to TROUBLESHOOT an audio amplifier training device, given the required test equipment, schematic diagram, and a prefaulted audio amplifier. Faults to be limited to open or shorted components; no more than one fault per problem. Remove/replace a similar component on a practice card. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21.5.42.10 IDENTIFY the conditions under which a push-pull amplifier may be used selecting the correct statement (with regard to power output) from a list of four choices. 100% accuracy is required.

21.5.42.10.1 IDENTIFY the electrical characteristic of a transistor that is "cut off" by selecting the most correct statement from a choice of four statements. 100% accuracy is required.

21.5.42.10.2 IDENTIFY the electrical characteristics of a transistor that is "saturated" by selecting the most correct statement from a choice of four statements. 100% accuracy is required.

21.5.42.10.3 DEFINE Class A bias by selecting the correct definition from a list of four choices. 100% accuracy is required.

21.5.42.10.4 DEFINE Class B bias by selecting the correct statement from a list of four choices. 100% accuracy is required.

21.5.42.10.5 OBSERVE the cut off and saturation states of a transistor by measuring the collector and base biasing voltages, given an oscilloscope, a training device and a job program. 100% accuracy is required.

OVERVIEW

21.5.42.10.6 OBSERVE class A and class B biasing by viewing the output of a transistor amplifier, given an oscilloscope, a training device, and a job program. 100% accuracy is required.

21.5.42.10.7 IDENTIFY basic push-pull amplifier configurations by selecting a schematic of a push-pull amplifier configuration from a choice of four schematics. 100% accuracy is required.

21.5.42.10.8 IDENTIFY the purpose of a phase splitter circuit or device by selecting the correct statement from a list of four choices. 100% accuracy is required.

21.5.42.10.9 SELECT those circuits containing a phase splitter, given four schematic circuit diagrams. 100% accuracy is required.

21.5.42.11 DESCRIBE a complementary-symmetry amplifier by selecting the correct description from a list of four choices. 100% accuracy is required.

21.5.42.11.1 IDENTIFY those circuits not containing a phase splitter, given four schematic circuit diagrams. 100% accuracy is required.

21.5.42.11.2 VERIFY the proper operation of a push-pull amplifier by viewing its operation, given an oscilloscope, a training device, and accessories. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON V

Basic Transistor Amplifier Circuit Analysis

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Audio/Visual Response Sheet Twenty One-V
Job Program Twenty One-V-1 "Transistor Amplifier Analysis"
Job Program Twenty One-V-2 "Transistor Amplifier Analysis"
Progress Check

Additional Material(s):

Audio/Visual Twenty One-V "Basis Transistor Amplifier Operational Characteristics"

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING SUPERVISOR: HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

SUMMARY
LESSON V

Basic Transistor Amplifier Circuit Analysis

In this lesson you will learn the two limits (cutoff and saturation) of a transistor, and the operating bias at which a transistor circuit may be designed to function (class A or class B). You will also cover three new circuits: push-pull amplifiers, phase-splitters and complementary-symmetry push-pull amplifiers.

Cutoff

Transistors are sometimes biased so they will not conduct (reverse biased).

When a transistor is reverse biased, the transistor is said to be cutoff. Since the base voltage will prevent current flow at cutoff, the transistor appears open between emitter and Vcc. For this reason you will measure source voltage (Vcc) across a cutoff transistor (See Figure 1).

Saturation

Saturation is the limit you reach when you increase forward bias until the transistor's conduction no longer increases. The transistor is then conducting as hard as it can (see Figure 1).

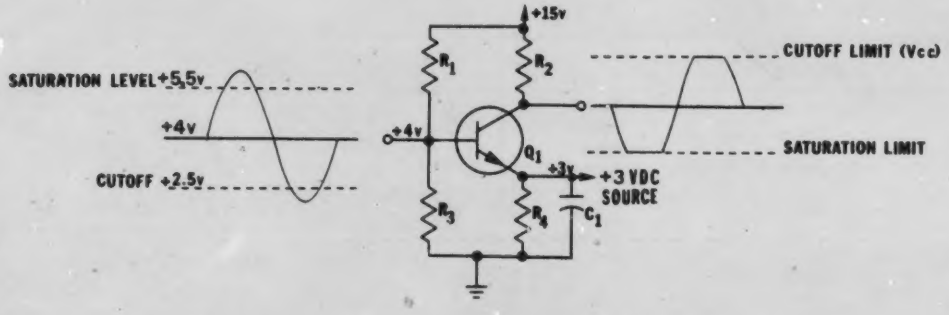


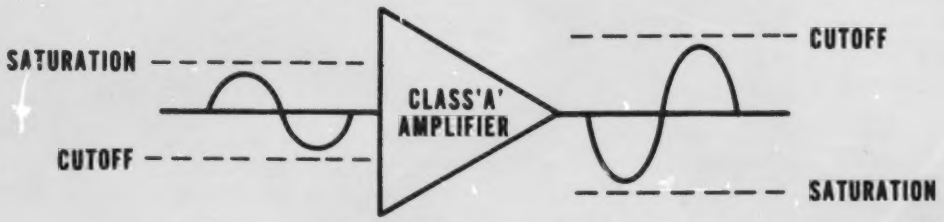
Figure 1

A saturated transistor acts almost like a short circuit. Nearly all of the Vcc will appear across the load resistor (R_L).

Relative to cutoff and saturation, there are four (4) classes of bias, but we will discuss only two of the classes in this lesson.

Class A

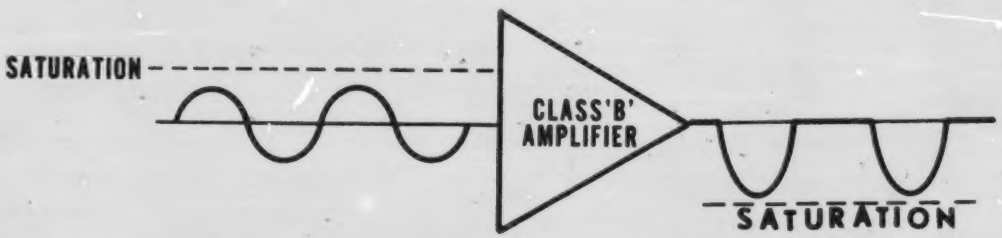
All the circuits you have studied have been Class A biased. The signal at the collector looks like the input signal, but it is larger and sometimes of opposite phase (Figure 2). In class A bias, the transistor conducts midway between cutoff and saturation with no signal input.



CLASS A AMPLIFIER
Figure 2

Class B

Class B bias sets the base bias at or just below the cutoff voltage of the transistor. This prevents the amplifier's conduction until the proper input signal is applied (see Figure 3).



CLASS B BIAS
Figure 3

Depending on whether we use NPN or PNP transistors, the circuit will amplify the positive or negative portions of the input signal.

Phase-Splitter

Some circuits we use require two input signals 180° out of phase but the same in amplitude. For this purpose we use a phase-splitter. See Figure 4.

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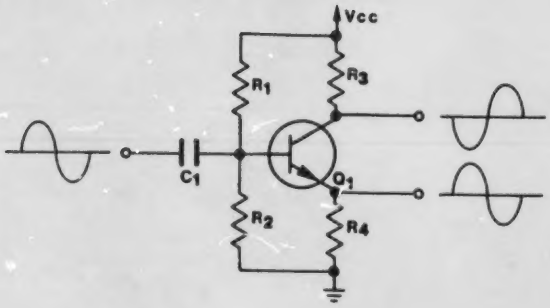
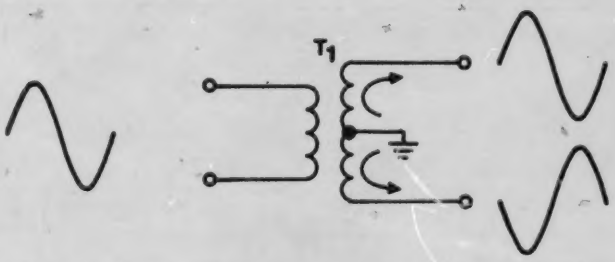


PHASE-SPLITTER
Figure 4

The transistor in a phase-splitter circuit will be forward (class A) biased. The collector resistor and the emitter resistor will be of equal value so their voltage drops will be equal. Since the transistor circuit causes phase reversal of the input signal at the collector, the two output signals (collector and emitter) will be 180° out of phase.

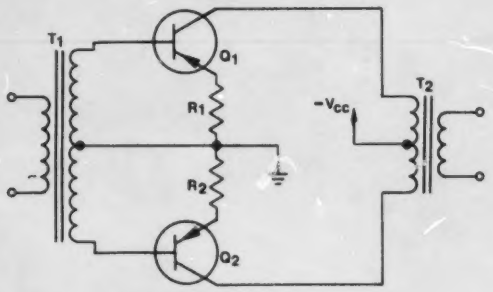
A center-tapped transformer will also provide a phase-splitter output (see Figure 5). The center tap effectively allows the secondary to act like two separate windings that provide two output signals equal in amplitude and 180° out of phase.



TRANSFORMER USED AS PHASE-SPLITTER
Figure 5

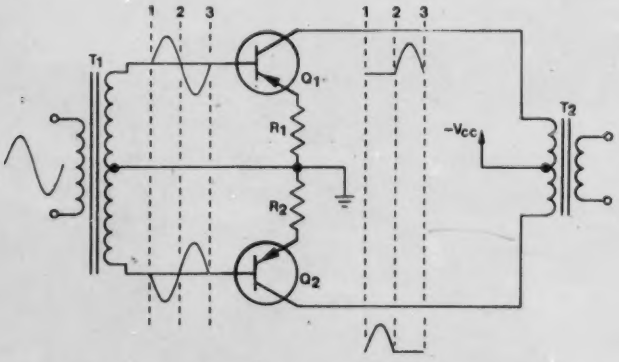
Push-pull Amplifier

A circuit that commonly uses a phase-splitter as an input is the push-pull amplifier (see Figure 6).



PUSH-PULL AMPLIFIER
Figure 6

Push-pull amplifiers provide high power amplification with minimum distortion. Basically a push-pull amplifier is two (2) common emitter circuits back to back. Most push-pull amplifiers are biased class B for efficient operation. The first circuit is formed by the top portion of T1, Q1, R1, and the top portion of T2. The other half is the bottom half of T1, Q2, R2, and the bottom half of T2. Each half of the output transformer (T2) acts as a collector load and output coupling device. The two signals out of our phase-splitter will cause one transistor to conduct and the other transistor to be in cutoff (see Figure 7). As the polarity of the signals changes, the transistor that was cut off will start to conduct and the other transistor will go into cutoff. Therefore, with class B bias on a push-pull amplifier you will have only one transistor conducting at a time.



PUSH-PULL AMPLIFIER WITH CURRENT WAVEFORMS
Figure 7

The amplified output signal from each transistor will be applied across its half of the transformer (T2). T2 will combine the two outputs of Q1 and Q2 and provide one output from its secondary, as shown in Figure 8.

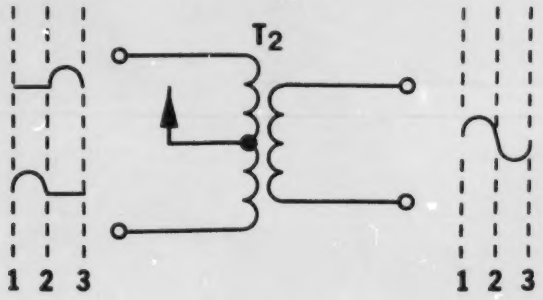
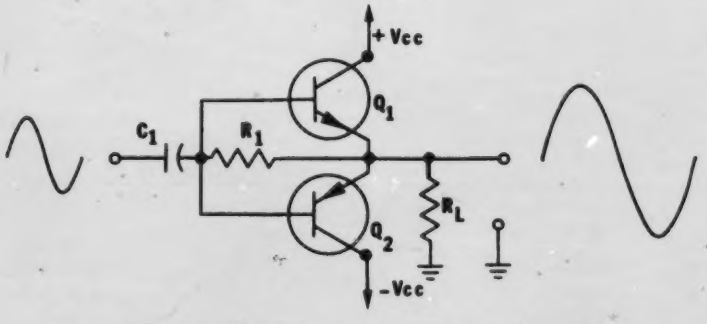


Figure 8

Now that we have studied common push-pull amplifiers and phase-splitters let's take a look at a push-pull amplifier that doesn't require a phase splitter. This type of push-pull amplifier is called a complementary-symmetry push-pull amplifier. A complementary-symmetry push-pull amplifier is simply a push-pull amplifier that uses an NPN transistor and a PNP transistor in conjunction, so we will need a power supply that provides both positive and negative voltages to properly bias a complementary-symmetry push-pull amplifier (see Figure 9).



COMPLEMENTARY-SYMMETRY PUSH-PULL AMPLIFIER
Figure 9

Just as common push-pull amplifiers can be biased class A or class B, so can the complementary symmetry push-pull amplifier. We normally use class B bias for more efficient operation of the circuit.

When we apply a positive signal to a class B biased complementary-symmetry push-pull amplifier, the NPN transistor (Q1) will conduct and the PNP transistor (Q2) will be cut off. The reverse is true when the input signal swings negative, Q2 will conduct and Q1 will be cut off.

The positive input signal will drive the NPN transistor and give a positive output signal across R_L; a negative input signal will drive the PNP transistor and provide a negative output signal across R_L. Because we use the common-collector configuration, we will not have phase inversion, and combining the output signals at R_L eliminates the need for an output transformer.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON V

Basic Transistor Amplifier Circuit Analysis

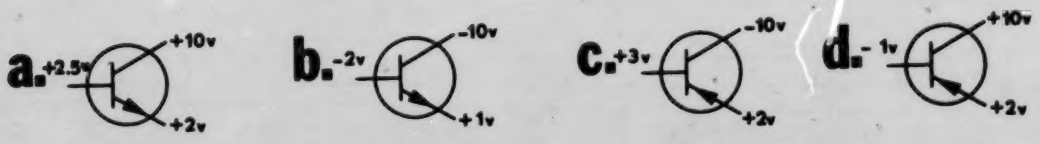
TEST FRAMES ARE 4, 8, 12, 19, 23, 26, 28. GO FIRST TO TEST FRAME 4 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. In the four previous lessons, you have identified a transistor, the voltage polarity at its elements that will cause it to conduct (biasing), and a few common transistor circuit configurations.

In this lesson you will learn the two limits of transistor operation (cut-off and saturation), and two classes of operating bias at which a transistor may be designed to function (class A or class B). You will also cover three new circuits: push-pull amplifiers, phase-splitter circuits, and complementary-symmetry amplifiers.

Up to this point, you have been concerned with biasing a transistor so it will conduct. You did this by applying the proper voltage to each element of a transistor. Not all transistors will be biased this way all the time. You will find some transistors to be reverse biased; that is, biased so they will not conduct.

Which transistor is forward biased, or biased to conduct?

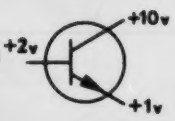


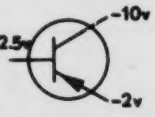
---

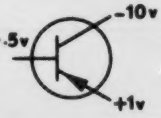
a. _____

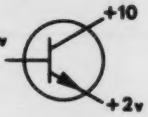
2. When a transistor is reverse biased, it is said to be at cutoff. The voltage on the base prevents current from passing through the transistor.

Which transistor is reverse biased (cutoff)?

a. 

b. 

c. 

d. 

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d.

3. With the base voltage preventing current flow, the transistor appears as an open between emitter and collector.

When measuring voltage across an open circuit, you will read source voltage. In this case you would read Vcc.

At cutoff, the transistor is (conducting/not conducting).

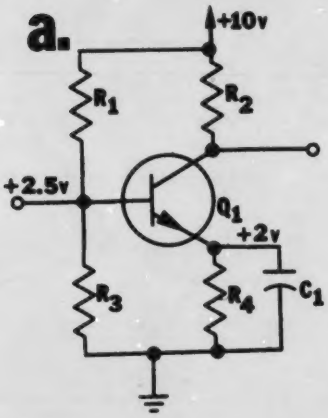
- -

not conducting

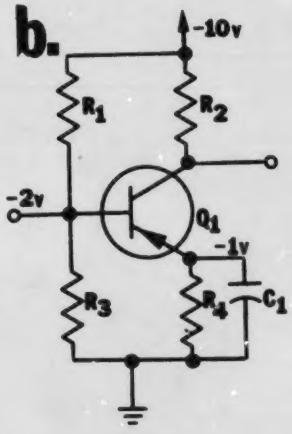
4. TEST FRAME

Which of the following amplifiers is at cutoff?

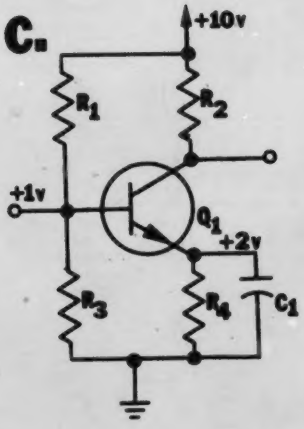
a.



b.



c.



- - - -

c.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 8. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 4 AGAIN.

5. When a transistor is at cutoff, no current will flow through it. The voltage sources applied to the transistors' emitters in Test Frame 4 insure the emitters will have a constant voltage level even if the transistors are at cutoff. The opposite to this condition is saturation, when the transistor is conducting as hard as it can. In this case, the transistor appears as a near short to the circuit.

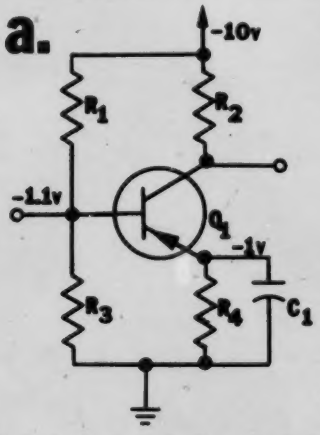
The extreme limits of transistor operation are _____ and _____.

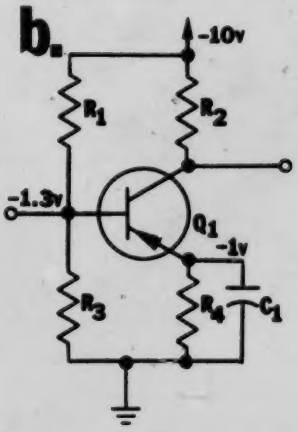
- -

cutoff and saturation (in any order)

6. The condition for a transistor to conduct is to have the base forward biased with respect to the emitter. Increasing forward bias at the base allows more current to flow through the transistor.

Which of the following amplifier circuits would have more current flowing through the transistor?





- -

b.

7. At some value of forward bias, current through the transistor will reach a maximum. This condition will depend on the type of transistor and the circuit design. Any further increase of base bias cannot increase the amount of current through the transistor.

When the transistor is operating at saturation, the largest amount of current possible is passing through it. The collector load resistor has not changed its value. Using Ohms law (E=IR), you can see that if current (I) increases and resistance (R) remains the same, the voltage (E) across the resistor must increase. The voltage across the resistor is limited by the amount of Vcc.

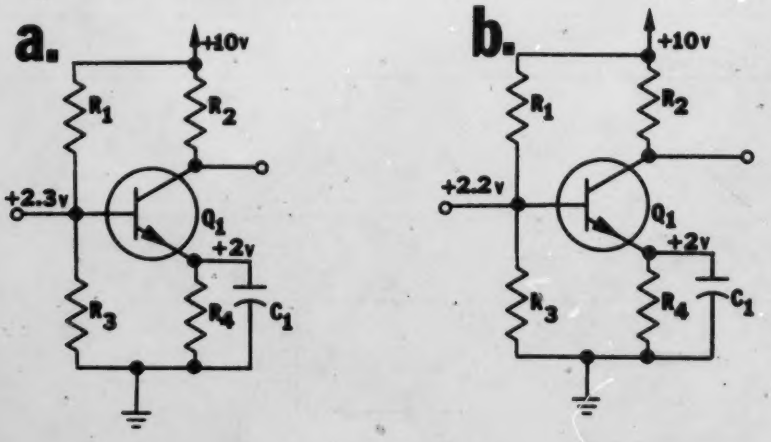
At saturation the current will be (large/small) through the transistor.

- -

large

8. TEST FRAME

Which circuit is closer to saturation?



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(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

a.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 12. OTHERWISE, GO BACK TO FRAME 5 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 8 AGAIN.

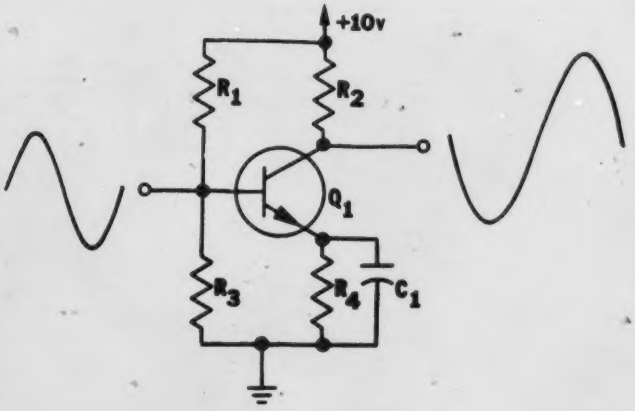
9. When a transistor is saturated, it appears as a near short to the circuit. Nearly all of Vcc will appear across the load resistor (RL). At this time the collector will be closer to emitter voltage than at any other time.

If the voltage across the load resistor is about equal to Vcc, the transistor is at _____.

- -

saturation

10. You have learned the limits of cutoff and saturation transistor operation. Between these limits we have four classes of bias. Here we will discuss only two of these classes. The first is Class A. Up to now, the circuits you have studied used class A bias. The sine wave at the collector looked like the input sine wave, but larger as shown in Figure 1.



CLASS A AMPLIFIER
Figure 1

Class A amplifiers operate between what two limits? _____.

- -

cutoff and saturation (either order)

11. Class A bias is centered between cutoff and saturation. This point of operation forward biases the amplifier enough that the input signal peak amplitudes will not drive the amplifier into either limit.

Class A amplifiers amplify (all/part/none) of the input signal.

- -

all

12. TEST FRAME

Which of the below conditions exists in class A amplifiers?

a. Current flows through the transistor at all times.
b. Current flows through the transistor only when a signal is applied.
c. Current by-passes the transistor when a signal is applied.
d. Current never flows through the transistor.

- -

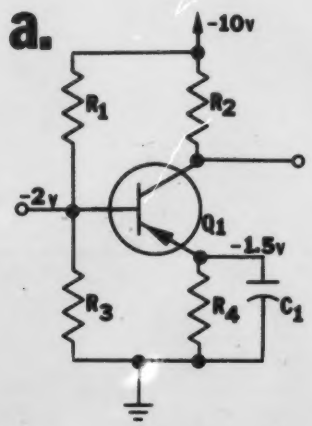
(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

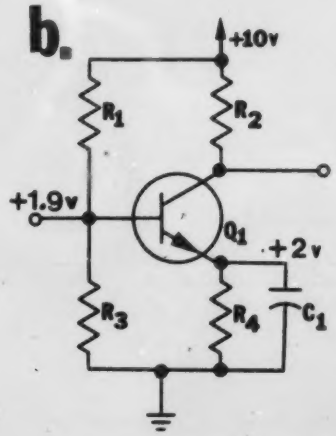
a. Current flows through the transistor at all times.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO TO TEST FRAME 15. OTHERWISE, GO BACK TO FRAME 9 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

13. The second class of operation, and the last we will discuss here, is referred to as Class B. For this class of bias the base voltage is set at or just below the cutoff voltage for the transistor. Class B bias prevents the amplifier's conducting until the proper input signal is applied.

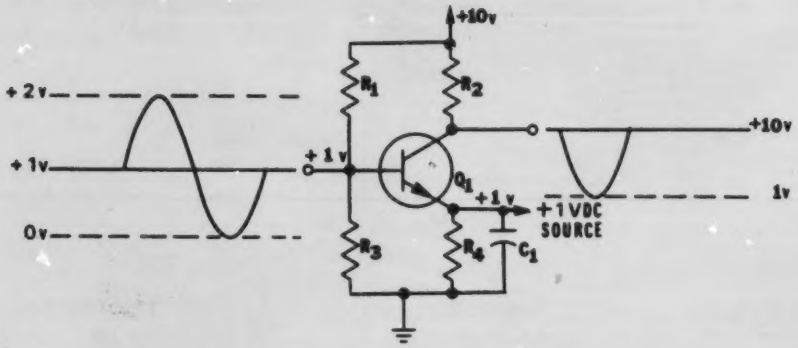
Which of the following circuits is class B biased?





b.

14.



Class B Bias
Figure 2

The circuit in Figure 2 is a class B biased (NPN) amplifier. Only when the input signal rises above positive one volt will the amplifier conduct. On the other hand, when the input signal passes below positive one volt the transistor is reverse biased and cut off. Therefore only the positive portion of the input signal will be amplified. If the transistor used is a PNP type, then the negative portion of the input will cause the amplifier to conduct.

When the transistor is operating at class B bias, the transistor is

a. never cutoff.
b. operating between cutoff and saturation.
c. biased at or just below cutoff.
d. always reversed biased.

- -

c. biased at or just below cutoff.

15. TEST FRAME

Which of the below conditions exists in a class B amplifier?

a. Current flows through the transistor at all times.
b. Current flows through the transistor only when a proper signal is applied.
c. Current bypasses the transistor when a signal is applied.
d. Current never flows through the transistor.

- -

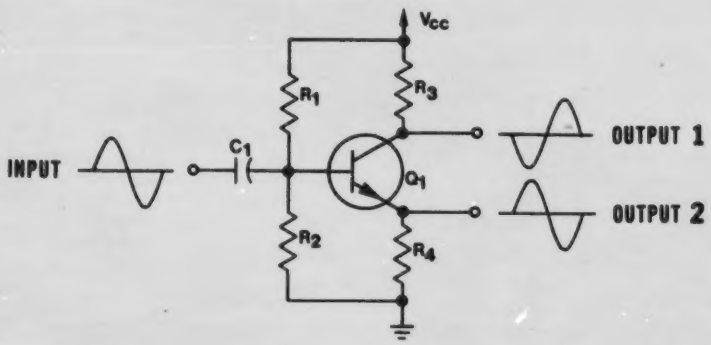
(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

b. Current flows through the transistor only when a proper signal is applied.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER YOU MAY GO TO TEST FRAME 19. OTHERWISE, GO BACK TO FRAME 13 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 15 AGAIN.

Phase-Splitters

16. Some circuits we use require two inputs 180° out of phase, but of equal amplitude. For this purpose we use a phase-splitter. See Figure 3.



PHASE-SPLITTER
Figure 3

The transistor in the phase-splitter circuit will always be forward biased. This will allow both peaks of the input sine wave to control the current through the transistor.

Phase-splitter circuits will be class (A/B) biased?

- -

A

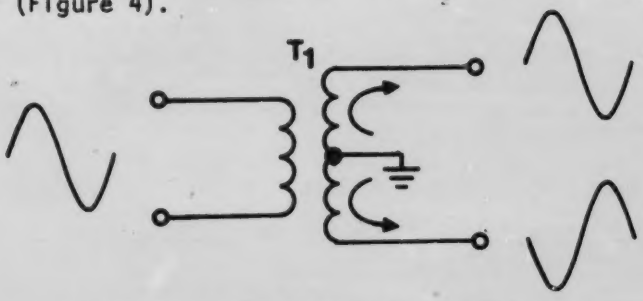
17. The collector resistor and the emitter resistor will be of equal resistance. With the same current flowing through both resistors, their voltage drops will be equal. Since the amplifier gives a phase reversal at output #1, the two output signals will be 180° out of phase (Figure 3).

The output signals are taken from the transistor's _____ and _____.

- -

collector and emitter (either order)

18. In the previous circuit we used a transistor to perform phase-splitting. Another way to provide the two needed waveforms is to use a center-tapped transformer (Figure 4).



TRANSFORMER USED AS PHASE-SPLITTER
Figure 4

As you may remember from the power supply module, the center tap effectively allows the secondary to act like two separate windings.

With the center tap as reference, the two signals from the secondary winding will be equal in amplitude and 180° out of phase.

The outputs from a center-tapped transformer will be (in/out of) phase, and (equal/unequal) in amplitude.

- -

out of, equal (in that order)

19. TEST FRAME

What is the function of a phase-splitter circuit?

a. To provide two equal signals 180° out of phase.
b. To provide two equal in-phase signals.
c. To increase the frequency of the input signal.
d. To increase the frequency of the output signal.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

a. To provide two equal signals 180° out of phase.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 23. OTHERWISE GO BACK TO FRAME 16 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 19 AGAIN.

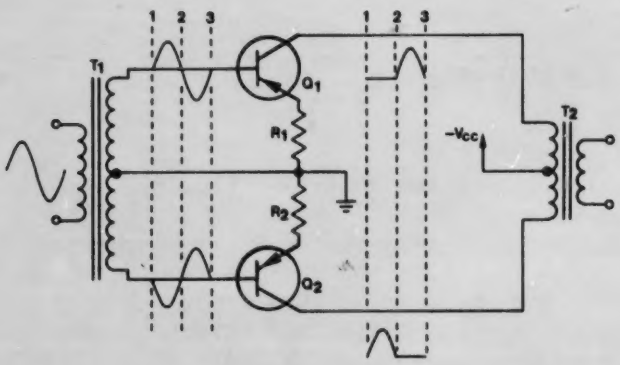
20. A circuit that uses phase-splitters as an input is a push-pull amplifier. Push-pull amplifiers are used because they provide high power amplification without distortion. Basically a push-pull amplifier is two common emitter circuits back to back (see Figure 5). They are usually class B biased. The first circuit is from -Vcc through half of T2's primary, transistor Q1, the emitter resistor (R1), to ground. The other half of the push-pull is from -Vcc through the second transistor (Q2) to ground. Each half of the output transformer acts as a collector load.

Push-pull amplifiers can be considered as two common _____ circuits connected back to back.

- -

emitter

21. Class B bias holds a transistor at or near cutoff and only the proper signal polarity will cause the transistor to conduct. In this case only the negative swing of the input sine wave will forward bias the transistor and cause it to conduct. With the two equal sine waves at the bases 180° out of phase as shown in Figure 5, the bottom transistor (Q2) will conduct during the first half cycle and the top transistor (Q1) will conduct during the second half cycle.



PUSH-PULL AMPLIFIER WITH CURRENT WAVEFORMS
Figure 5

In class B biased push-pull amplifiers the transistors conduct (at the same time/at different times).

- -

at different times

22. The amplified output signal from each transistor will be applied across its half of the output transformer, and the waveform across the secondary winding will swing in one direction the first half cycle, then in the opposite direction the second half cycle (Figure 6).

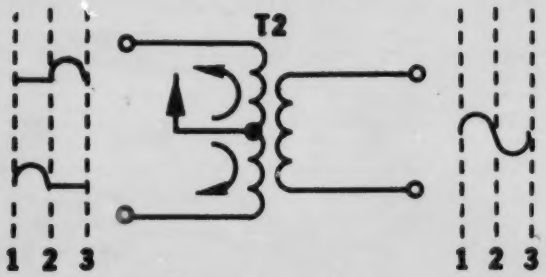


Figure 6

The output sine wave from the push-pull amplifier will be similar to the input sine wave but it will contain much more power.

True or False:

We use a center tapped transformer for the output of a push-pull amplifier to produce a smooth sine wave at the output from the two signals of the transistors.

- -

True

23. TEST FRAME

What is the function of a push-pull amplifier?

a. To provide high voltage gain.
b. To provide high output power.
c. To provide a large D.C. voltage.
d. To provide current regulation.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

b. To provide high output power.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 26. OTHERWISE, GO BACK TO FRAME 20 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 23 AGAIN.

24. Now that we have studied common push-pull amplifiers and phase-splitters, let's take a look at a push-pull amplifier that doesn't require a phase-splitter. This type of push-pull amplifier is called a complementary-symmetry push-pull amplifier.

A complementary-symmetry push-pull amplifier is simply a push-pull amplifier that uses an NPN transistor and a PNP transistor in conjunction.

No response required.

25. We know from lesson II that NPN and PNP transistors work the same except that they require opposite polarity voltages for proper operation; that NPN transistors require a Positive Vcc and PNP transistors require a Negative Vcc. To meet these requirements we will need a power supply that provides both negative and positive voltages to operate a complementary-symmetry push-pull amplifier.

In a complementary symmetry push-pull amplifier we use:

a. Two PNP transistors.
b. Two NPN transistors.
c. One PNP transistor and one NPN transistor.

- -

c. One PNP transistor and one NPN transistor.

26. TEST FRAME

A complementary-symmetry push-pull amplifier is:

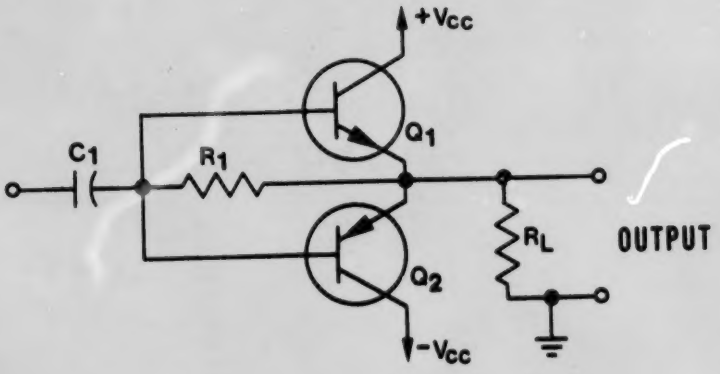
a. A push-pull amplifier used to complement the input signal.
b. A push-pull amplifier that uses an NPN transistor and a PNP transistor.
c. A series of push-pull amplifiers.
d. Two push-pull amplifiers hooked back to back.

- - - -

b. A push-pull amplifier that uses an NPN transistor and a PNP transistor.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 28. OTHERWISE, GO BACK TO FRAME 24 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 26 AGAIN.

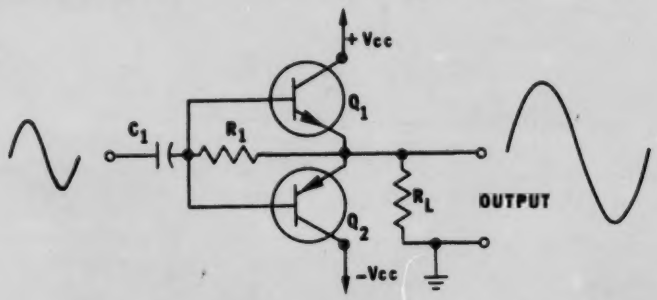
27. Now let's take a look at a schematic of a complementary-symmetry push-pull amplifier (Figure 7).



COMPLEMENTARY SYMMETRY PUSH-PULL AMPLIFIER
Figure 7

Just as common push-pull amplifiers can be biased class A or B, so can the complementary-symmetry push-pull amplifier be biased class A or B. In most cases we will bias a complementary-symmetry push-pull amplifier class B for more efficient operation.

When a negative going signal is applied, Q2 will conduct and Q1 will be cut off. With a positive signal in, we will drive the NPN transistor and the result will be a positive signal across R_L. A negative input signal will drive the PNP transistor and cause a negative output signal across R_L. Because the circuit is basically a common collector configuration, we will not have phase inversion in a complementary-symmetry push-pull amplifier, and we will not need a transformer to combine the output signal from the two halves of the circuit (Figure 8).



COMPLEMENTARY-SYMMETRY PUSH-PULL AMPLIFIER WITH INPUT AND OUTPUT SIGNALS
Figure 8

When we apply a positive signal to a class B biased complementary-symmetry push-pull amplifier, the NPN transistor (Q1) will conduct and the PNP transistor (Q2) will be in what state?

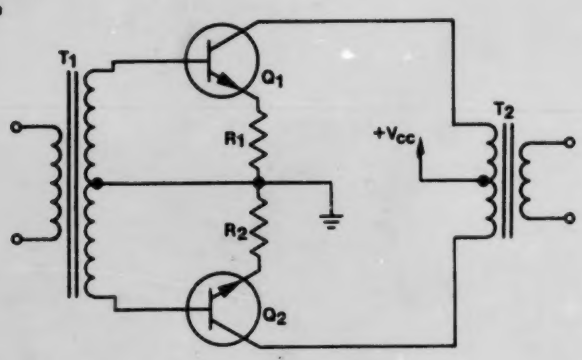
- -

cutoff

28. TEST FRAME

Match the following circuits with their proper names.

1.



a. COMMON BASE AMPLIFIER

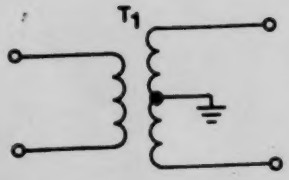
b. PUSH-PULL AMPLIFIER

c. VOLTAGE REGULATOR

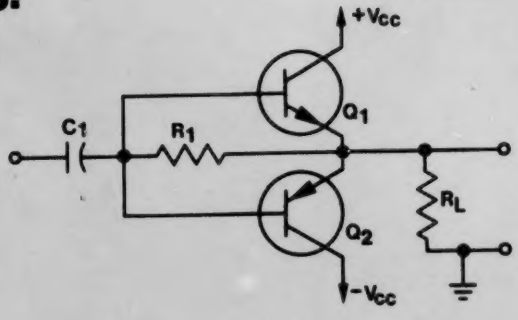
d. COMPLEMENTARY-SYMMETRY PUSH-PULL AMPLIFIER

e. PHASE-SPLITTER

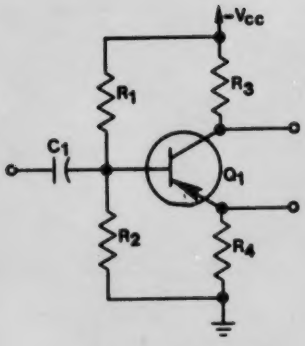
2.



3.



4.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

1, b; 2. e; 3. d; 4. e

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON V MODULE TWENTY ONE. OTHERWISE GO BACK TO FRAME 27 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 28 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

NARRATIVE
LESSON V

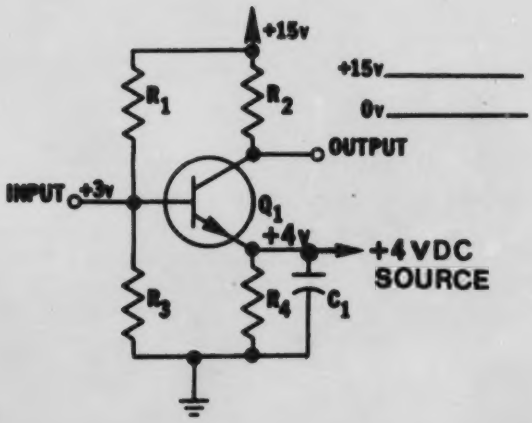
Basic Transistor Amplifier Circuit Analysis

In the four previous lessons you have studied transistors, transistor bias, and a few common transistor circuit configurations.

In this lesson you will learn the two limits (cutoff and saturation) of transistor operation, and the operating bias at which a transistor circuit may be designed to function (Class A or Class B). You will also cover three new circuits: push-pull amplifiers, phase-splitters, and complementary symmetry push-pull amplifiers.

CUTOFF

Until now, you have been concerned with biasing for continuous conduction of the transistor which requires forward bias. Not all transistors will be biased for constant conduction; they are sometimes biased so they will not conduct. This condition requires that the base not be forward biased with respect to the emitter as shown in Figure 1.



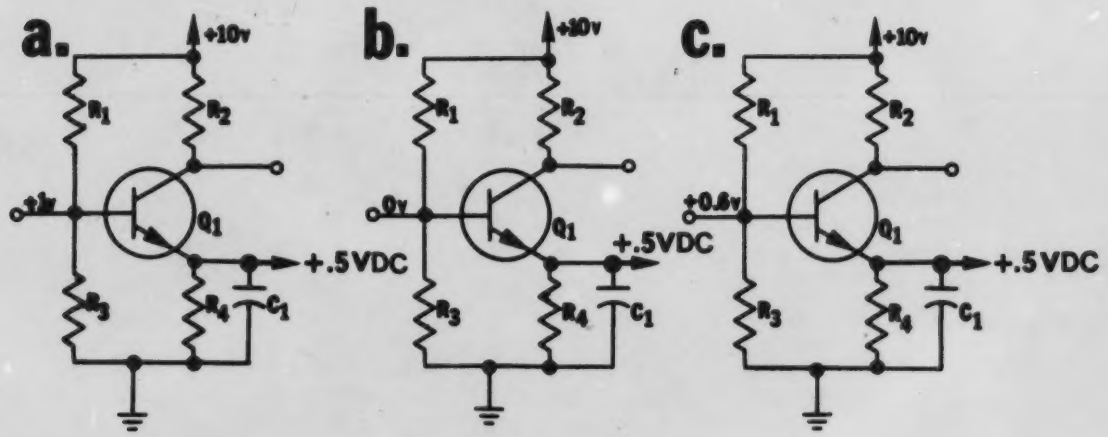
BASE-EMITTER JUNCTION REVERSE BIAS
Figure 1

When a transistor is reverse biased, the transistor is said to be cutoff. At cutoff the base voltage level will prevent current flow through the transistor, making the transistor appear as an open circuit between the emitter and the collector.

Notice that the emitter of Q1 is tied to a +4 vdc source. This will insure that the emitter of Q1 is held at a constant 4 vdc even when Q1 is cutoff (no current flow through the transistor).

When measuring voltage across an open circuit you will read source voltage. When the transistor is cutoff, you will read Vcc.

Which circuit illustrated below has its transistor biased at cutoff?



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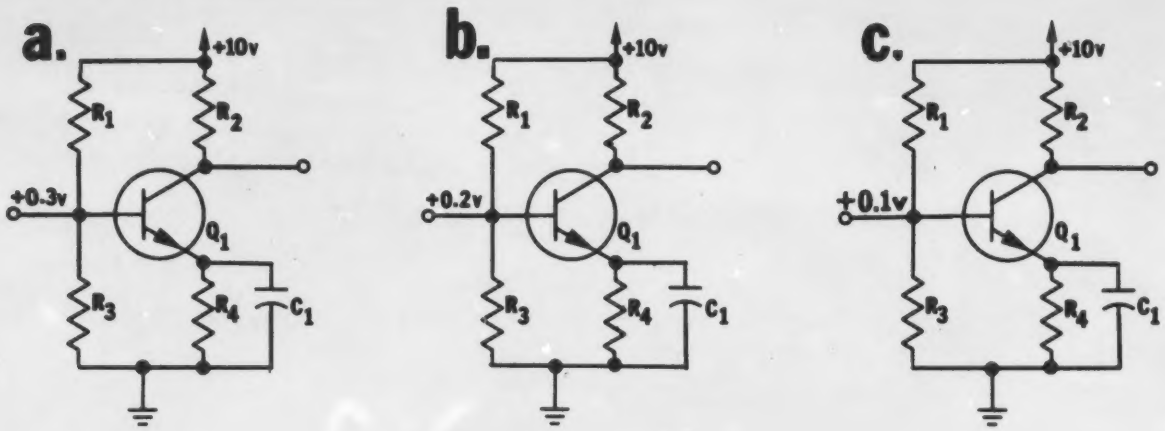
The transistor conduction is maximum for the applied Vcc.

Which circuit illustrated below is closer to saturation. (All transistors are of the same type.)



- -

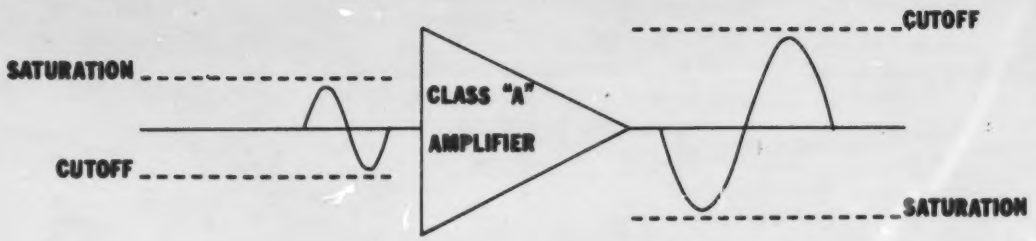
a.

A saturated transistor acts almost like a short circuit. Nearly all of the Vcc will appear across the load resistor (R2). At this time the voltage at the collector of the transistor will be closer to the emitter voltage than at any other time.

There are four classes of bias, but in this lesson we will discuss only two of these classes: Class A and Class B.

Class A Bias

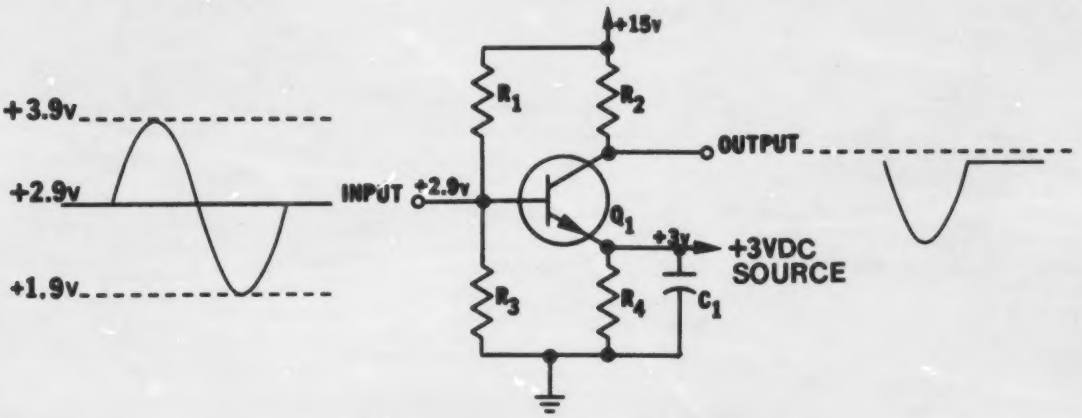
All the circuits you have studied have been class A biased. The waveform at the collector is the same shape as the input waveform, but it is larger. Class A bias centers the operating point of the transistor between cutoff and saturation, so that all portions of the input signal are amplified as long as the input signal does not exceed the limits for cutoff and saturation, see Figure 3.



CLASS A BIAS
Figure 3

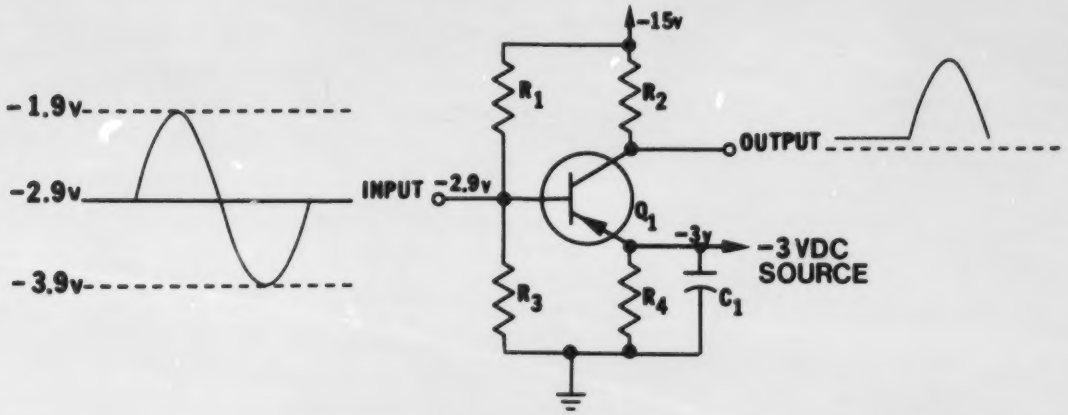
Class B Bias

The second class of bias we will study is class B. Class B bias sets the base bias at or just below the cutoff voltage of the transistor. This prevents the amplifier's conducting until the proper input signal is applied, as shown in Figure 4.



CLASS B BIAS
Figure 4

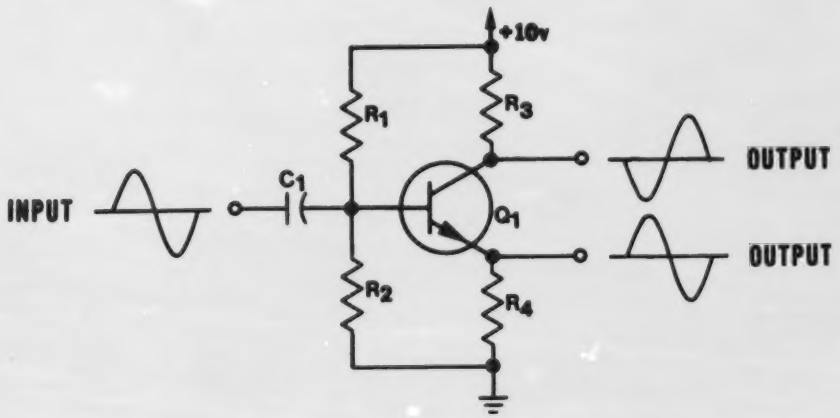
The amplifier circuit in Figure 4 is biased class B. The amplifier will conduct only when the input signal rises above positive 2.9 volts; therefore, only the positive portion of the input signal will be amplified. If the transistor used is PNP, then only the negative portion of the input signal will allow the transistor to conduct. See Figure 5.



PNP TRANSISTOR WITH CLASS B BIAS
Figure 5

Phase-Splitters

Some circuits we use require two inputs 180° out of phase. For this purpose we use a phase-splitter circuit. See Figure 6.



PHASE-SPLITTER
Figure 6

A phase-splitter is a circuit or device that takes a single input and supplies two signals of equal amplitude, but 180° out of phase. The transistor in a phase-splitter circuit will be forward (Class A) biased; this will allow both peaks of the input sine wave to control the current through it.

The collector resistor (R3) and the emitter resistor (R4) will be of equal value. With the same current flow through both resistors the voltage drops will be equal. Since the transistor causes phase reversal of the input at the collector, the two output signals will be 180° out of phase.

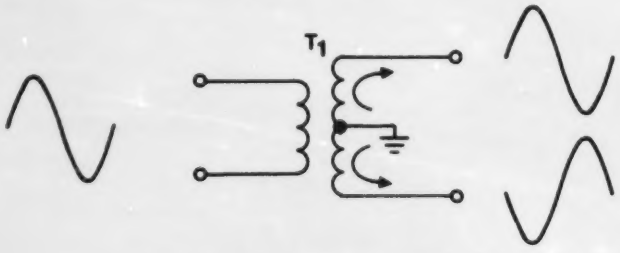
What is the function of a phase-splitter circuit?

a. To provide two equal signals 180° out of phase.
b. To provide two equal in-phase signals.
c. To increase the frequency of the input signal.
d. To increase the frequency of the output signal.

- -

a. To provide two equal signals 180° out of phase.

In the previous circuit we used a transistor to perform phase-splitting Another way to provide the needed waveform is to use a center-tapped transformer. As shown in the power supply module, the center tap effectively allows the secondary to act like two separate windings. See Figure 7.

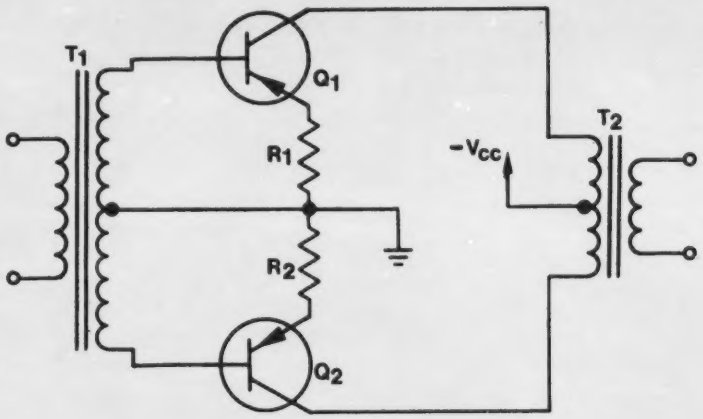


TRANSFORMER AS PHASE-SPLITTER
Figure 7

With the center tap as reference, the two signals from the secondary windings will be equal in amplitude and 180° out of phase.

Push-Full Amplifiers

Push-Pull amplifiers are used because they provide high power amplification with minimum distortion. Basically a push-pull amplifier consists of two common-emitter amplifier circuits connected back to back, as shown in Figure 8.

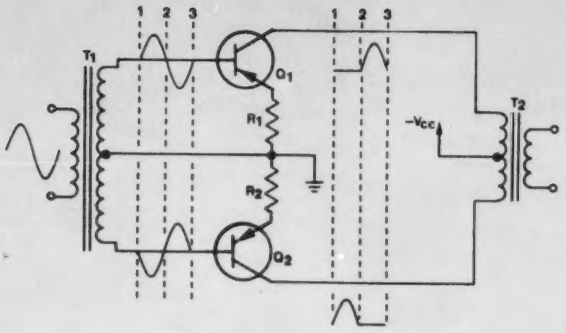


PUSH-PULL AMPLIFIER
Figure 8

The first circuit is from -Vcc through the upper half of transformer T2 through transistor (Q1) and emitter resistor R1 to ground. The other half of the push-pull is through -Vcc to the second transistor (Q2). Each half of the output transformer (T2) acts as a collector load and transformer action combines the signals from each half into a smooth output signal. Push-pull amplifiers are normally biased class B. The input section of a push-pull amplifier is a phase-splitter.

Since class B bias holds the transistors at or near cutoff, each transistor will conduct for only part of its input signal (see Figure 9). In this case, only the negative swing of the wave applied to its base will forward bias either transistor and cause it to conduct. The two signals at the base are equal in amplitude but, 180° out of phase. Thus, the bottom transistor (Q2) will conduct for the first half cycle (at T1's primary), and the top transistor (Q1) will conduct for the second half cycle.

NOTE: The collector waveforms shown are <u>current</u> waveforms. The <u>voltage</u> waveforms shown by an oscilloscope would be complete sine waves due to transformer action.



PUSH-PULL AMPLIFIER CURRENT WAVEFORMS
Figure 9

In push-pull amplifiers, the transistors conduct (at the same time/at different times).

- -

at different times

The amplified output signal from each transistor will be applied across its half of the transformer (T2). The secondary wave will swing in one direction the first alternation, and then in the opposite direction for the second alternation.

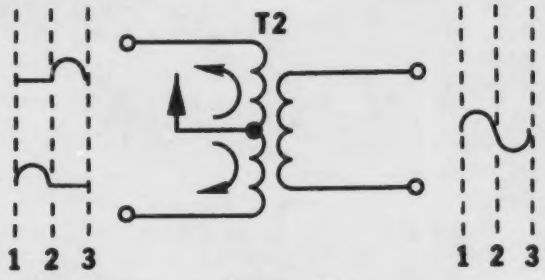


Figure 10

The output from the push-pull amplifier will be similar to the input, but much more powerful. (More power may mean higher current rather than higher voltage).

Now that we have studied common push-pull amplifiers and phase-splitters, let's take a look at a push-pull amplifier that doesn't require a phase-splitter. This type of push-pull amplifier is called a complementary-symmetry push-pull amplifier.

A complementary symmetry push-pull amplifier is simply a push-pull amplifier that uses an NPN transistor and a PNP transistor in conjunction. We know from lesson II that NPN and PNP transistors work the same, but they require voltages of opposite polarity for proper operation. NPN transistors require a positive Vcc; PNP transistors require a negative Vcc. Therefore we will need a power supply that provides both negative and positive voltages to operate a complementary-symmetry push-pull amplifier.

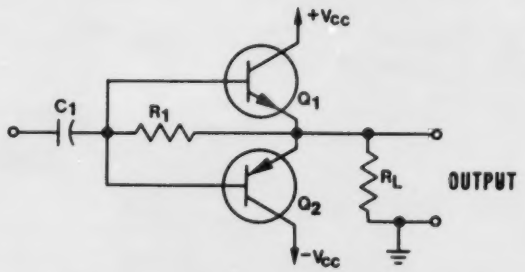
A complementary-symmetry push-pull amplifier is:

a. A push-pull amplifier used to complement the input signal.
b. A series of push-pull amplifiers.
c. A push-pull amplifier that uses an NPN transistor and a PNP transistor.
d. Two push-pull amplifiers hooked back to back.

- -

c. A push-pull amplifier that uses an NPN transistor and a PNP transistor.

Now, let's take a look at a schematic of a complementary-symmetry push-pull amplifier (Figure 11).



COMPLEMENTARY-SYMMETRY PUSH-PULL AMPLIFIER
Figure 11

Just as common push-pull amplifiers can be biased class A or B, so can the complementary-symmetry push-pull amplifier be biased class A or B. In most cases we will use class B bias for more efficient operation of the circuit.

When we apply a positive input signal to a class B biased complementary-symmetry push-pull amplifier, the NPN transistor (Q1) will conduct and the PNP transistor (Q2) will be cutoff. The reverse is true when the signal swings negative; Q2 will conduct and Q1 will be cutoff. When the input signal is positive, we will drive the NPN transistor and the result will be a positive signal across R_L. A negative input signal will drive the PNP transistor and cause a negative output signal across R_L.

Since the signals are combined at R_L, we do not need a transformer to combine the output signals for the two halves of the circuit. This provides considerable savings in cost and weight as compared to a standard push-pull amplifier, but gives the same power and efficiency advantages.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE-T

MULTI-ELEMENT VACUUM TUBES

STUDY BOOKLET

1 April 1977

OVERVIEW

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE-T

Multi-Element Vacuum Tubes

In this module you will learn that there are more kinds of tubes than just diodes. Adding a control grid to a diode makes a triode; add a screen grid and you will have a tetrode; then add a suppressor grid and you will have a pentode. You will learn how each of these grids affects the tube's operation. Special applications call for special tubes or power tubes. You will also compare the basic circuit configurations covered in transistors to their equivalent circuits with tubes.

For you to learn the above, this module has been divided into the following two lessons.

Lesson I - Multi-Element Vacuum Tubes
Lesson II - Vacuum Tube Circuit Configurations

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE-T

LESSON I

MULTI-ELEMENT VACUUM TUBES

1 April 1977

OVERVIEW
LESSON 1

Multi-Element Vacuum Tubes

In this lesson you will study multi-element tubes and learn the advantages and disadvantages of tubes and how added elements overcome these disadvantages.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21T.1.43 When the student completes this course, he will be able to IDENTIFY the operational similarities and differences that exist between tubes and transistors by comparing similar circuit applications. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21T.1.43.1 IDENTIFY the elements of a triode tube by selecting the correct name for each element, given a schematic symbol and four choices of names. 100% accuracy is required.

21T.1.43.2 IDENTIFY the method of controlling current flow through a triode to obtain signal amplification by selecting the correct statement from a set of four choices. 100% accuracy is required.

21T.1.43.3 IDENTIFY a solid state device having current flow characteristics most like a triode vacuum tube by selecting the correct device from a list of four choices. 100% accuracy is required.

21T.1.43.4 IDENTIFY a condition that will cause a triode vacuum tube to "cut off" by choosing the most correct statement from a set of four choices. 100% accuracy is required.

21T.1.43.5 IDENTIFY a condition that will cause a triode vacuum tube to "saturate" by choosing the most correct statement from a set of four choices. 100% accuracy is required.

21T.1.43.6 IDENTIFY the screen grid in a tetrode vacuum tube given a schematic symbol of a tetrode vacuum tube. 100% accuracy is required.

OVERVIEW

21T.1.43.7 IDENTIFY the function of a screen grid in a vacuum tube by selecting the correct statement from a set of four choices. 100% accuracy is required.

21T.1.43.8 IDENTIFY three major advantages a pentode tube has over a tetrode tube or a triode tube by selecting the statement containing all three advantages in it. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON 1

Multi-Element Vacuum Tubes

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Study Booklet:

Summary
Narrative

Student's Guide:

Audio/Visual Response Sheet Twenty One-T-1
Progress Check

Additional Material(s):

Audio/Visual Twenty One-T-1 "Multi-Element Vacuum Tubes:

Enrichment Material(s):

Fundamentals of Electronics, Vol. 2, NAVPERS 93400A-2

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING SUPERVISOR; HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

SUMMARY
LESSON 1

Multi-Element Vacuum Tubes

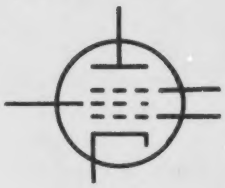
The diode vacuum tube contains two elements, but vacuum tubes are not restricted to just two elements; tubes that must do more than just rectify need three or more elements. Vacuum tubes (amplifiers) have three, four, five and more elements depending on what the tube is being used for. The most important, from the standpoint of usage, is the triode (Figure 1). Inserting a fine wire mesh or control grid between the cathode and the plate creates the three element tube; the triode. The control grid (like the transistor base) determines the amount of electron flow through the device.

Triode
Figure 1

Triodes are amplifying devices that function like NPN transistors. (NOTE: There is no tube equivalent to the PNP transistor. Current flow in a tube won't go that way.) Unlike the NPN transistor base, the control grid is normally operated at some negative potential. This is necessary because a positive control grid would not only draw current (which in tube amplifiers is bad) but would conduct so many electrons to the plate, that it would always be saturated and could not amplify. The control grid can also be placed at such a high negative potential, that no current will flow through the tube, a condition known as cut-off. The control grid has such a great effect on the triode that it has more control over plate current than does plate voltage, but the triode isn't fault free. It really doesn't work so well at high frequencies. (The rapid changes were more than the triode could handle.) For high frequencies, vacuum tube amplifiers utilize tetrodes and pentodes.

Tetrode
Figure 2

The tetrode (Figure 2) is a four element vacuum tube, with the fourth element inserted between the control grid and the plate. This element is called a screen grid. The screen grid acts as a shield and is normally operated at some positive voltage (typically 90 volts). Due to its shielding effect, the screen grid also has more effect on plate current than does plate voltage. The tetrode can handle the frequency, but it is not linear, which causes distortion in the output when a large input signal is applied. This non-linearity reduces the use of a tetrode as an amplifier. The solution to this problem is the pentode (see Figure 3).

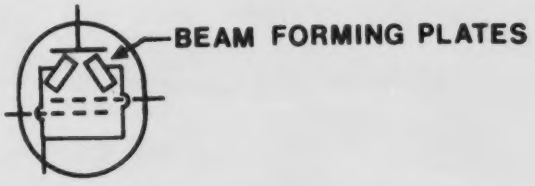


Pentode
Figure 3

The Pentode has a fifth element, placed between the screen grid and the plate. This fifth element is called a Suppressor Grid and it usually operates at the same potential as the cathode. It causes the plate current to rise uniformly with a proportional increase in plate voltage. The suppressor grid also increases the available gain and extends the frequency range beyond that of the tetrode.

Each of the multi-element vacuum tubes can be used in an amplifier circuit (radios, TV's) but they won't deliver the power required to drive a public address system or a radio transmitter. For this we use power tubes; power triodes, beam power tubes and power pentodes. The differences between power tubes and regular multi-element tubes are minimal. The basic differences are in the size of the internal elements. The elements for power tubes are larger.

Schematically, the only difference in presentation is the beam power tube (Figure 4). The beam power tube has all of the elements of a tetrode; plus, just above the screen grid, it has two beam forming plates.



Beam Forming Tube
Figure 4

The function of the plates is to concentrate the electrons into a small area. Functionally, the beam power tube is identical to the power pentode.

Schematically, all components are referred to with letter number combination. Resistors use "R", and capacitors use "C". Vacuum tubes use the letter "V".

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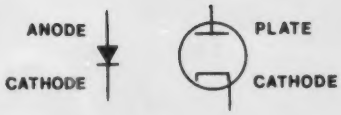
NARRATIVE
LESSON 1

Multi-Element Vacuum Tubes

We have determined that a diode has two elements. These two elements are: the plate and the cathode. When the cathode is negative with respect to the plate, the diode will conduct. The conclusion can be drawn that the vacuum tube diode and the transistor diode are functionally the same; they are used as rectifiers, they do not amplify, and they conduct current in only one direction. In 1907 Lee DeForest discovered that by placing a control grid, a small wire mesh, in the diode between the cathode and the plate, electron flow through the vacuum tube could be controlled. This control was accomplished by varying the potential on the control grid. Since there were three elements involved, the device was called a TRIODE.



Which element was added to the diode vacuum tube to make it a triode?

a. The base.
b. The control grid.
c. A second cathode.
d. The control plate.

- -

b. The control grid.

Electron flow through the triode is controlled by varying _____ voltage.

a. plate
b. cathode
c. control grid
d. base

- -

c. control grid

The triode is utilized as an amplifying device in the same manner as an NPN transistor. (Multi-element vacuum tubes have no equivalent to the PNP transistor.) Current, in the tube, will always flow from cathode to plate as in the NPN Transistor, as shown in Figure 1.

Figure 1

Current never flows from plate to cathode as in the PNP Transistor.

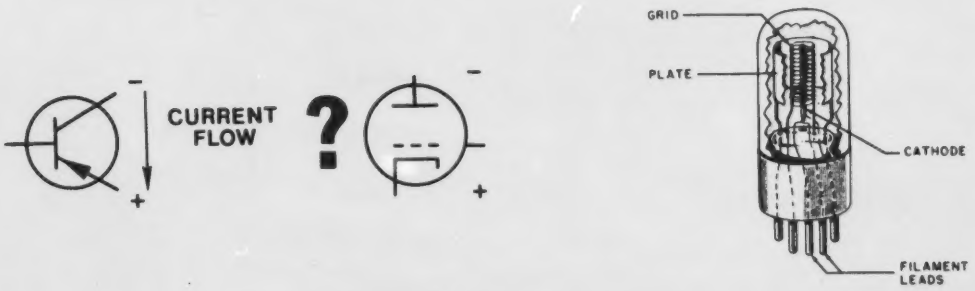


Figure 2

The illustration in figure 2 includes a cut-away view of the triode. It shows how the elements are situated inside the glass envelope.

Figure 3 illustrates an exploded view of the interior of the triode.

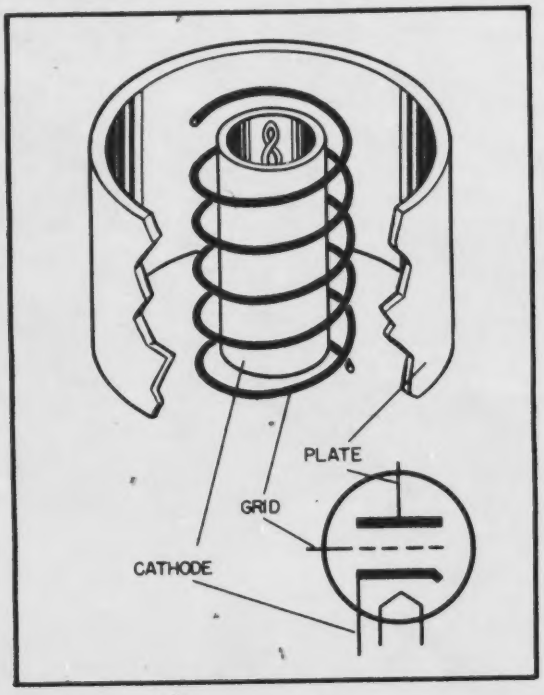


Figure 3

Using the illustration on the previous page, lets find out how a triode works. The control grid is normally operated at some negative potential with respect to the cathode; it is also physically placed much closer to the cathode than to the plate. Since the electrons must travel between the control grid wires, the potentials of both the control grid and the plate are effective in controlling plate current. The control grid, however, being closer to the cathode, has more control over plate current than plate voltage does. The control grid can be placed at such a high negative potential that no current will flow through the triode; (a condition referred to as cut-off) or the negative potential can be reduced to a point where all the available electrons at the tube's cathode flow to the plate and increasing plate voltage will not increase tube current. (A condition referred to as saturation.)

Current flow in a triode will be the same as current flow in

a. PNP transistors.
b. NPN transistors.
c. NPN and PNP transistors.

- -

b. NPN transistors.

Which of the following statements is most correct?

a. The control grid is normally operated at a negative potential with respect to the cathode, and at a positive potential with respect to the plate.
b. The control grid is the only element controlling plate current.
c. The control grid potential has more control of plate current than the plate potential.
d. The cathode is closer to the plate than is the control grid.

- -

c. The control grid potential has more control of plate current than the plate potential.

Triode tubes can be used in the same type circuits as three element NPN transistors. Triodes will use the same classes of bias as the three element transistor; namely Class A and Class B. Triodes work fine and last a long time, but there are some disadvantages; the most glaring is the bad things it does at high frequencies.

As the current through the triode increases, plate voltage tends to decrease which causes plate current to also tend to decrease. This is the general effect when a sine wave is placed on the control grid of a triode. At high frequencies these changes are so rapid the triode just can't keep up, causing signal distortion. It was discovered that if additional grids were used most of the problems could be alleviated. This led to the invention of the TETRODE (a four element tube) and the PENTODE (a five element tube).

The tetrode (figure 4) is a four element vacuum tube, with the fourth element placed close to the control grid, but between the control grid and the plate. The element, called a screen grid, compensates for some of the problems the triode encountered at high frequencies.

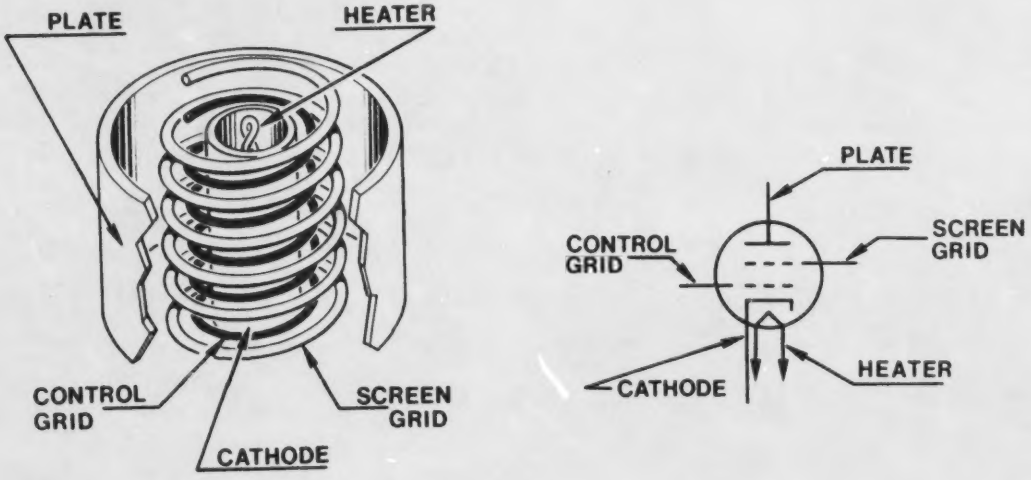


Figure 4

The screen grid is normally operated at some positive voltage (typically 90 volts) therefore acting as an accelerator for the electrons, and also as a shield between control grid and plate.

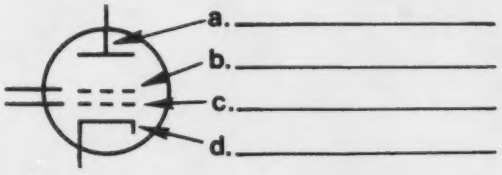
The addition of the screen grid provides a relatively constant voltage for the electrons emitted by the cathode. The screen grid also acts as a shield for the control grid and cathode against the electrostatic lines of force emitted by the plate. (So far, so good!)

Since fewer lines of force now exist between plate and cathode, changes in plate voltage have less effect on plate current, and, due to the shielding effect of the screen grid, the plate becomes merely a collector of electrons (similar to a photographic plate which collects light, but exercises no control over the amount of light it receives). In short, the screen grid voltage now will have more effect on varying plate current than variations in plate voltage will.

Just what the doctor ordered, right? Wrong! The tube was found to be non-linear. (In other words, when grid voltage increased, plate current wouldn't increase at the same proportional rate.) The non-linearity was no problem as far as frequency was concerned, but it caused a highly distorted output when large input signals were used. This limited the uses of the tetrode as an amplifier.

NOTE: With a large signal input the electrons, accelerated by the screen grid, would bounce off of the plate; not all of the electrons, but enough to cause a lot of distortion.

Name the four elements of a tetrode:



- -

a. Plate; b. Screen grid; c. Control grid; d. Cathode

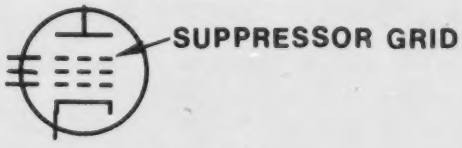
Which of the following statements is most correct?

a. The tetrode is a non-linear device, but has wide applications as an amplifier.
b. The screen grid acts as a shield between the control grid and cathode.
c. The screen grid has more effect on plate current than plate voltage does.
d. The tetrode has little distortion with a large signal input.

- -

c. The screen grid has more effect on plate current than plate voltage does.

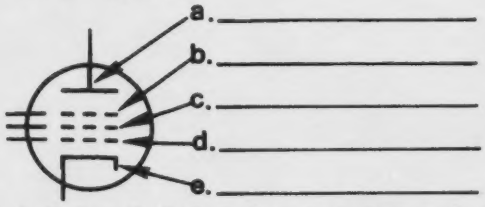
The solution to the tetrode's distortion problem was (you guessed it!) to add another grid. The new grid is placed between the screen grid and the plate. The grid is called a Suppressor grid and the vacuum tube is called a Pentode, see Figure 5.



Pentode
Figure 5

The suppressor grid is usually at some negative potential with respect to the plate and screen grid (normally at the same potential as the cathode). Being negative, the suppressor grid serves to repel or suppress the electrons that bounce off of the plate. It also slows down the electrons approaching the plate but this action does not interfere with electron flow from cathode to plate. Thus, at any given screen grid voltage, plate current rises smoothly from zero to its saturation point as control grid voltage is uniformly increased. The addition of the suppressor grid also increases the available gain and extends the frequency range.

Name the elements of a Pentode:



- -

a. Plate; b. Supressor grid; c. Screen grid; d. Control grid; e. Cathode.

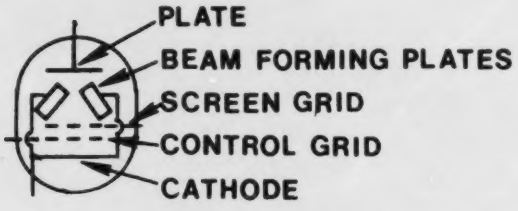
What advantages does a pentode have over a tetrode or a triode?

a. Linear current increases, lower power requirements, and extended frequency range.
b. Extended frequency range, linear current increase, and greater available gain.
c. Greater available gain, limited frequency range, and increased plate voltage.
d. Linear current increases, extended frequency range, and decreased plate voltage.

- -

b. Extended frequency range, linear current increase, and greater available gain.

Each of the multi-element vacuum tubes can be used in an amplifier circuit and can do a very good job. (Your older radios and TV's are proof of that.) Yet, these tubes don't put out enough power to drive a public address system or a radio transmitter. For these applications we use POWER TUBES; power triodes, beam power tubes, and power pentodes. The difference in regular multi-element tubes and power tubes is the size of the internal elements. Power tubes have much larger elements. The power triode and the power pentode are schematically displayed the same as regular triodes and pentodes. The beam power tube is slightly different. The beam power tube schematic symbol is shown in Figure 6.



Beam Power Tube
Figure 6

The beam power tube has beam forming plates which keep the electrons concentrated in a small area. Notice that these plates are at the same potential as the cathode. Functionally the beam power tube is identical to the power pentode.

What is the primary difference between power tubes and regular multi-element tubes?

a. Size of the tube.
b. Number of control elements.
c. Size of the tube elements.
d. Plate voltage requirements.

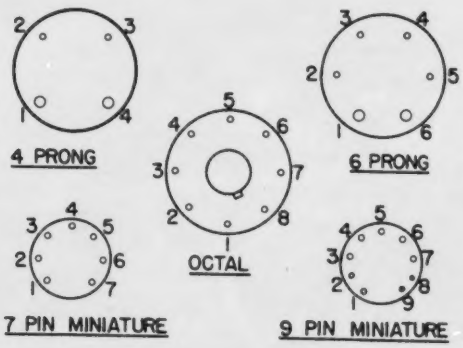
- -

c. Size of the tube elements.

Regular multi-element type tubes may have more than one functional group of components in the same tube envelope. In other words, you can have diode-triodes, or duo-triodes,

and all kinds of pretty wild combinations. These tubes are packaged this way to cut down on space and, in some cases, for special circuit application. When you see one on a schematic, remember -- it's a real tube and not a figment of the printer's imagination.

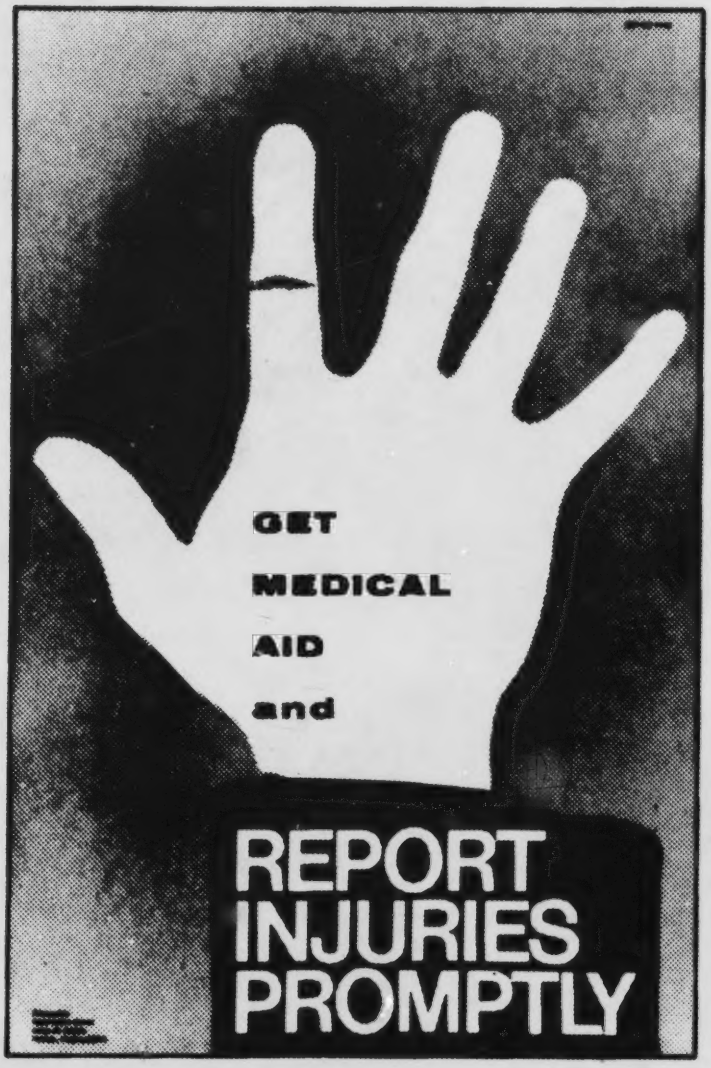
Because of the large number of tube types in use, it has become necessary to establish a system of identifying the socket connections. In diagrams of circuits that include tubes, it is common practice to show the socket connections, which in turn correspond to the connecting pins at the bottom of the tube. Also, to be consistent with general practice, all references to socket connections and tube pin numbering are made from bottom views of sockets and tubes. Here are a few examples of tube pin numbering.



Tube Pin Numbering
Figure 7

Schematically, all components are referred to with letter-number combination. Resistors use "R", and capacitors use "C". Tubes use the letter "V".

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.


GET
MEDICAL
AID
and
REPORT
INJURIES
PROMPTLY

BASIC ELECTRICITY AND ELECTRONICS

MODULE TWENTY ONE-T

LESSON II

VACUUM TUBE CIRCUIT CONFIGURATIONS

1 April 1977

OVERVIEW
LESSON 11

Vacuum Tube Circuit Configurations

In this lesson you will learn how multi-element tubes are used in circuits and how they compare to their transistor counterparts.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

21T.2.43 When the student completes this course, he will be able to IDENTIFY the operational similarities and differences that exist between tubes and transistors by comparing similar circuit applications. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, he will be able to:

21T.2.43.9 IDENTIFY by selecting, the solid state amplifier configuration (CB,CE, CC) most like a grounded cathode amplifier, given four choices only one of which is correct. 100% accuracy is required.

21T.2.43.9.1 IDENTIFY by selecting the output voltage waveform of a grounded cathode amplifier circuit given a schematic diagram of a grounded cathode amplifier, an input waveform, and a set of four waveform choices only one of which is correct. 100% accuracy is required.

21T.2.43.10 IDENTIFY by selecting the solid state amplifier circuit (CB, CC, CE) most like a grounded grid amplifier circuit, given four choices, only one of which is correct. 100% accuracy is required.

21T.2.43.10.1 IDENTIFY by selecting the output voltage waveform of a grounded grid amplifier circuit given a schematic diagram of a grounded grid amplifier, an input waveform, and a choice of four waveforms, only one of which is correct. 100% accuracy is required.

21T.2.43.11 IDENTIFY by selecting the solid state amplifier circuit (CB, CC, CE) most like a cathode follower circuit given four statements, only one of which is correct. 100% accuracy is required.

OVERVIEW

21T.2.43.11.1 IDENTIFY by selecting the output voltage waveform of a cathode follower amplifier circuit given a schematic diagram of a cathode follower amplifier, an input waveform, and a choice of four output waveforms, only one of which is correct. 100% accuracy is required.

21T.2.43.12 IDENTIFY by selecting a schematic diagram of a tube-type phase splitter circuit, given four schematic diagrams, only one of which is correct. 100% accuracy is required.

21T.2.43.13 IDENTIFY by selecting a schematic diagram of a tube-type push-pull amplifier circuit, given four schematic diagrams, only one of which is correct. 100% accuracy is required.

21T.2.43.14 VERIFY the proper operation of vacuum tube amplifier configurations (CC, CG, CP) by observing the input and the output of the amplifier given an oscilloscope, training device, and a job program. 100% accuracy is required.

21T.2.43.15 OPERATE a tube tester by testing various types of tubes given a tube tester, a box of tubes, and a job program. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON II

Vacuum Tube Circuit Configurations

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Study Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Job Program Twenty One-T-II-I "Vacuum Tube Circuit Configuration"
Job Program Twenty One-T-II-II "Operation of the TV-7 D/U Tube Tester"
Progress Check

Additional Material(s):

Audio/Visual Twenty One-II "Operation of the TV-7 D/U Tube Tester"

Enrichment Material(s):

Electronics Installation and Maintenance Book, Electronic Circuits, NAVSHIPS 0967-000-0120, section 5

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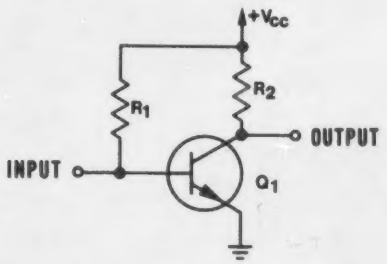
SUMMARY
LESSON 11

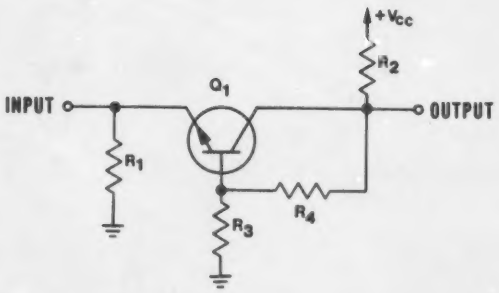
Vacuum Tube Circuit Configurations

In Module Twenty One, Transistor Amplifiers, you were introduced to the three basic amplifier configurations.

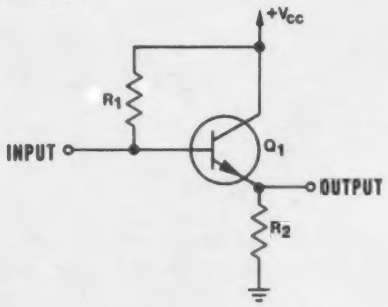
They are the common-emitter,



the common-base,



and the common-collector.



Each circuit has a particular function. Tubes are used in circuits that compare with these simple amplifiers.

The first is the grounded-cathode (see Figure 1). (NOTE: B+ indicates source voltage.)

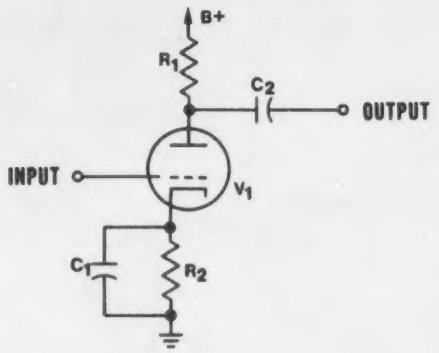


Figure 1

As in the common-emitter amplifier where the input signal was applied to the base, the input signal is now applied to the control grid. The output signal is taken from the plate. This circuit has 180° phase inversion with good voltage and power gain. The grounded-cathode tube amplifier is the most extensively used vacuum tube circuit configuration.

The second circuit configuration is the grounded-grid amplifier (see Figure 2). As in the common-base circuit where the input signal is applied to the emitter,

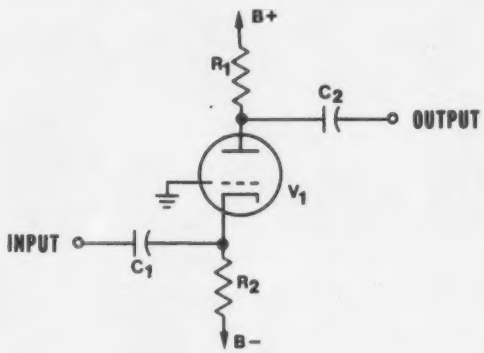


Figure 2

the input is applied to the cathode, and the output is taken from the plate. The grounded-grid amplifier, like the common-base amplifier, has no phase inversion. This circuit configuration is generally used in higher frequency applications. The grounded-grid has a lower power gain than the grounded-cathode but it has a higher voltage gain.

The third type of circuit configuration is the grounded-plate (Figure 5). This circuit is similar to the common-collector circuit. A more common name for this circuit is cathode follower.

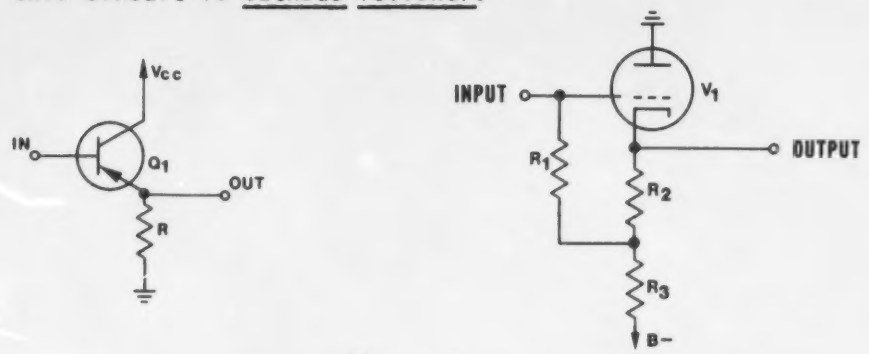


Figure 3

The input is applied to the control grid and the output is taken from the cathode. Cathode followers are used in impedence matching because of their high input impedance and low output impedance. The voltage gain of a cathode follower is less than unity (1), and the power gain is less than that of the grounded-cathode amplifier. Cathode followers have no phase inversion between input and output signals.

The three circuits we just compared were all single-ended. The next circuit is a push-pull tube circuit (Figure 4). As in the transistor circuit, the tube push-pull amplifier will have transformer coupling into and out of the circuit.

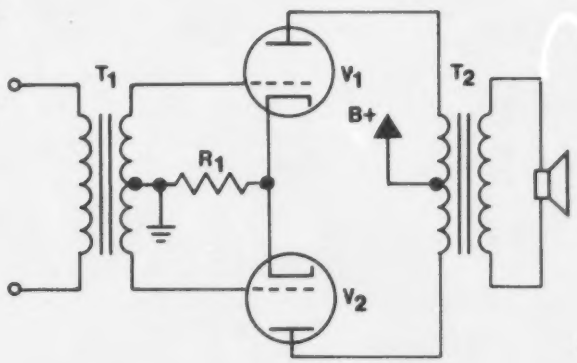


Figure 4

As in the transistor push-pull amplifier, the secondary of the input transformer, T1, provides the matched tubes with two identical signals 180° out of phase. The amplified signal out of one tube is 180° out of phase with the other tube's output, thus providing the push-pull effect across the primary of the output transformer, T2.

In the push-pull circuit you have two inputs, one to each tube, and one large output. The phase-splitter circuit (Figure 5) has one input signal and two output signals. The phase-splitter, therefore, can be used as an input circuit for a push-pull amplifier.

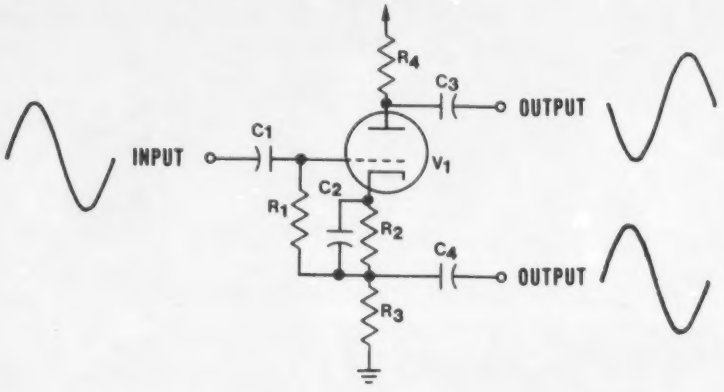


Figure 5

The input sine wave is applied to the control grid of the tube. The output signals, one from the plate and one from the cathode, will be about the same size as the input signal. The cathode signal will be in phase with the input while the plate signal is 180° out of phase with both signals.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

Vacuum Tube Circuit Configurations

TEST FRAMES ARE 6, 10, 13, 19, AND 22. AS BEFORE, GO FIRST TO TEST FRAME 6 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. In Module Twenty One, Transistor Amplifiers, you learned that transistors are replacing vacuum tubes in modern equipment. This is true; however, there are some things that tubes can do better than transistors. So some kinds of equipment use mostly tubes, and it will be a while before a transistorized equipment replaces them.

In the first few frames we will compare several transistor circuits with their equivalent vacuum tube circuits.

1. The first of the vacuum tube circuits we will cover is the grounded-cathode amplifier (Figure 1). This circuit is similar to the common-emitter transistor amplifier. Power supply voltage in tube circuits is referred to as B+ instead of Vcc as is found in transistorized circuits.

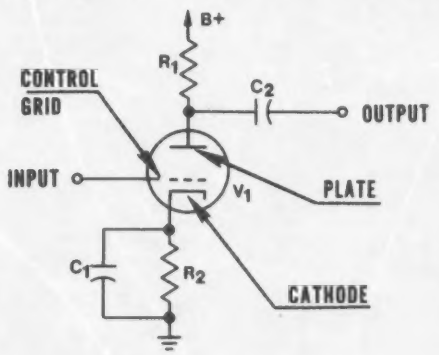


Figure 1

Like the common-emitter configuration of transistors, the grounded-cathode amplifier is the most widely used of the tube amplifiers.

The grounded-cathode circuit can be compared to the _____ transistor circuit.

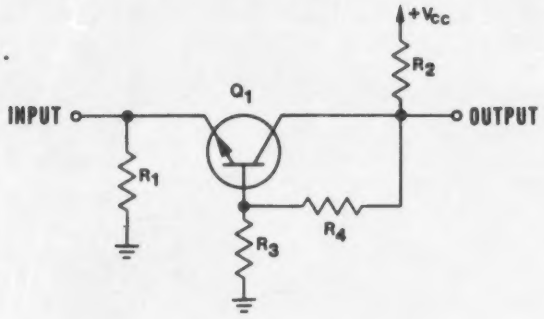
- -

common-emitter

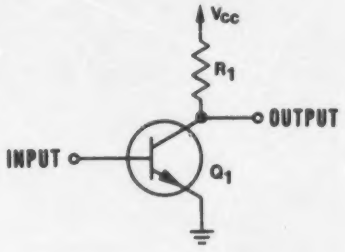
2. The grounded-cathode amplifier provides good voltage and power gain. That is, with a small signal applied to the control grid, a much larger signal is present at the plate.

Which of the following circuits is comparable to the grounded-cathode tube amplifier?

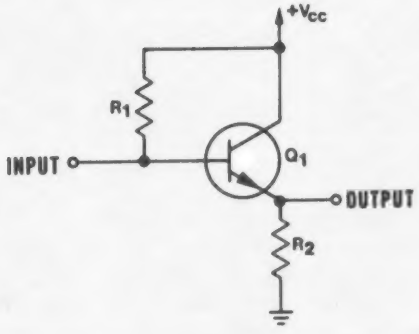
a.



b.



c.



- -

b.

3. In transistors we stated that a usual signal input was approximately 0.3 volts. In vacuum tubes, the input voltage can range up to 20 volts and higher. The output signal will be larger than the input signal. The amount will depend on the circuit configuration, but its peak-to-peak value can never be larger than the plate voltage.

Input signals to tube circuits are usually (smaller/larger) than input signals to transistorized circuits.

- -

(larger)

4. The grounded-cathode and common-emitter circuits have another similiarity -- phase inversion. Both circuits have an inverted output signal as compared to the input signal (Figure 2).

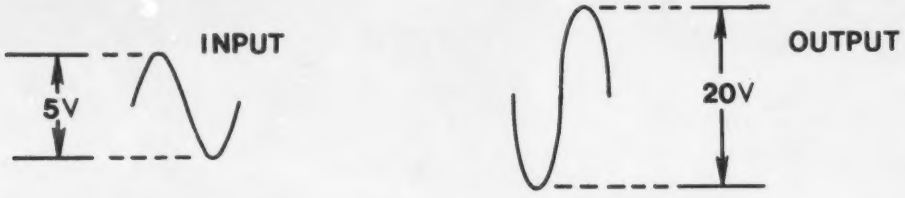


Figure 2

The output signal's maximum amplitude depends on the _____.

- -

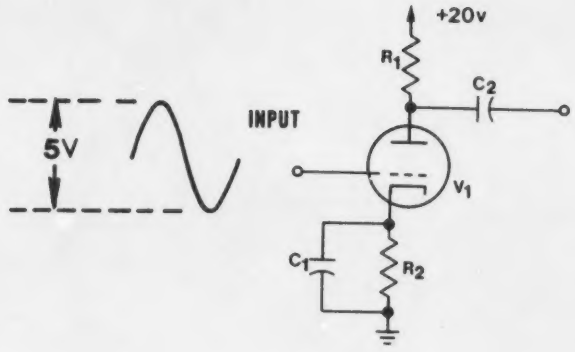
plate voltage supply (B+)

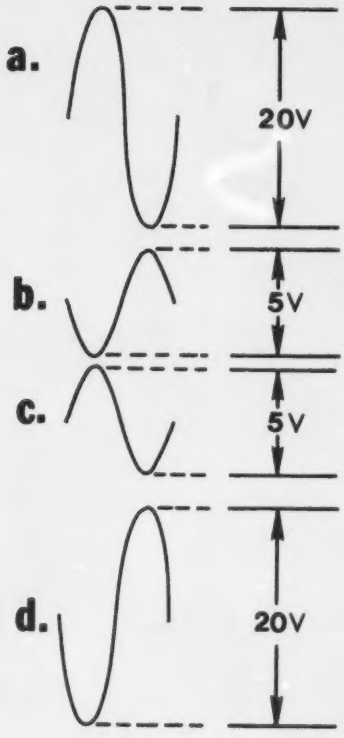
5. What is the phase relationship between the input and output signals of a grounded-cathode tube amplifier?

- -

180° out of phase (or words to that effect.)

6. Which of the following output signals would you expect from a grounded-cathode circuit?





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THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.

d.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 10. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 6 AGAIN.

7. The second circuit configuration that we will examine is the grounded-grid amplifier (see Figure 3). This circuit is similar to the common-base transistor configuration.

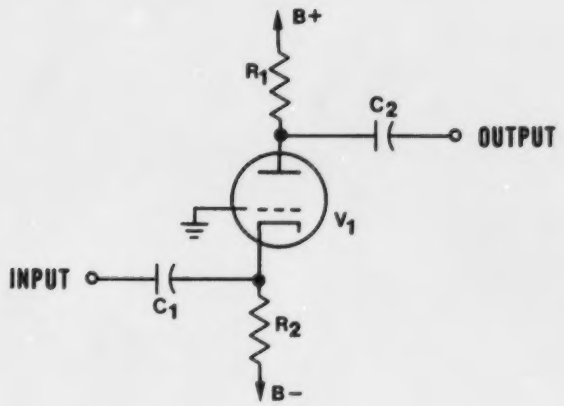


Figure 3

The grounded-grid amplifier is more generally found in high frequency applications.

The grounded-grid amplifier configuration is comparable to which transistor configuration?

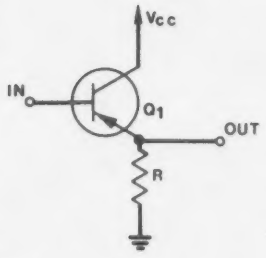
- -

common-base

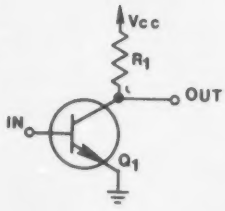
8. The grounded-grid circuit has a higher voltage gain than the grounded-cathode, yet it has a lower power gain.

Which of the transistor circuits illustrated below is comparable to the grounded-grid amplifier?

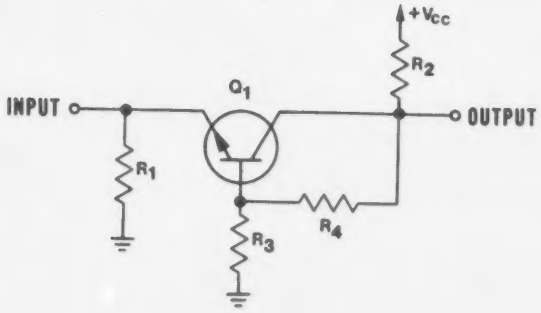
A.



B.



C.



- -

c.

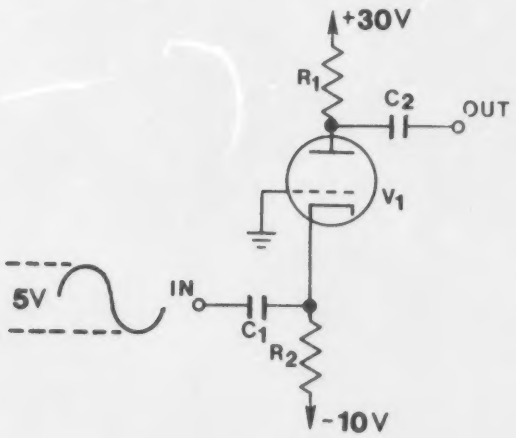
9. When the input signal is applied to the cathode and is taken from the plate, there is no phase inversion between the input and output signals.

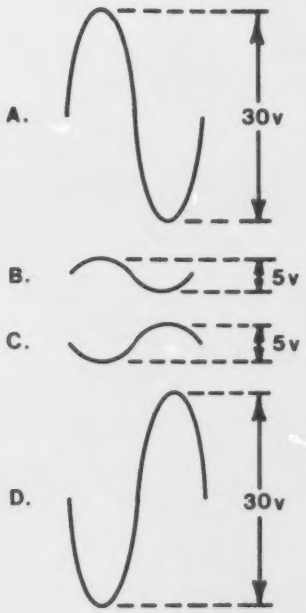
The grounded-grid circuit has a (smaller/larger) voltage gain than the grounded-cathode amplifier.

- -

(larger)

10. Which of the output signals illustrated below would you expect to see from a grounded-grid amplifier?



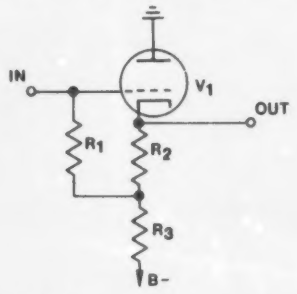


THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.

a.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 13. OTHERWISE, GO BACK TO FRAME 6 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 10 AGAIN.

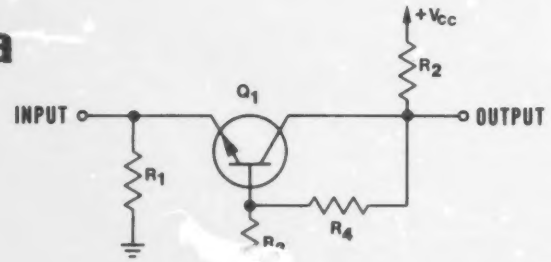
11. The last of the single-ended vacuum tube amplifiers we will compare is the grounded-plate. This circuit is more commonly called a cathode-follower. The cathode-follower gets its name because the signal at the cathode follows, or does the same, as the signal at the control grid. When the signal on the grid increases, the signal from the cathode increases.



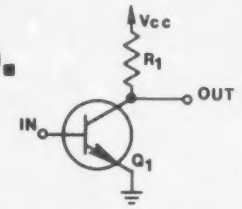
The cathode-follower tube amplifier is comparable to the common-collector amplifier. The input is applied to the control grid and the output is taken from the cathode.

Which of the following circuits is comparable to the cathode-follower?

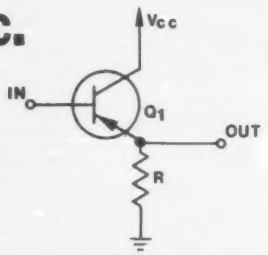
a



b.



c.



c.

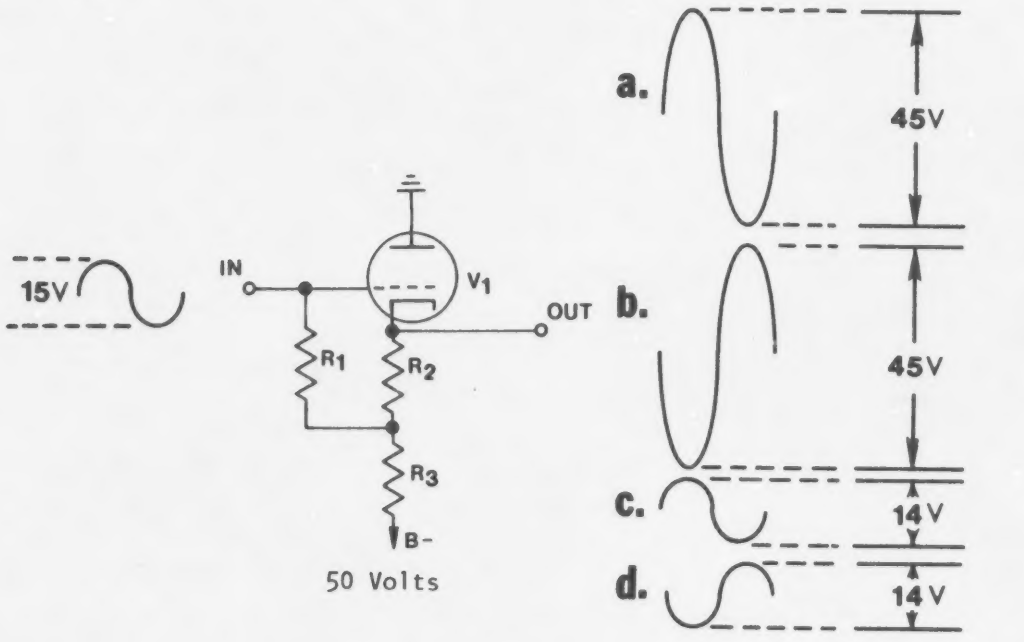
12. The output signal from the cathode-follower will be slightly smaller than the input signal. The voltage gain is, therefore, less than unity (1). Cathode-followers, like grounded-grid amplifiers, do not invert the signal.

The cathode-follower configuration is similar to the _____ transistor configuration.

- -

common-collector

13. Which of the output signals illustrated below would you expect from a cathode-follower?



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THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.

c.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 19. OTHERWISE, GO BACK TO FRAME 11 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 13 AGAIN.

14. The three configurations we just studied are commonly used, single-ended type amplifiers. They will be found, one way or another, in most vacuum tube equipments. Two other circuits that are very common are the push-pull amplifier and the phase-splitter.

First, we will discuss the push-pull amplifier (see Figure 5).

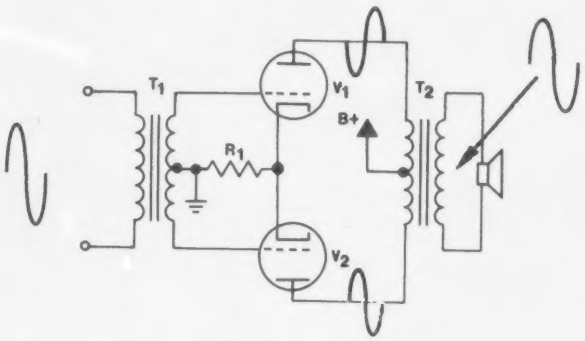


Figure 5

Push-pull amplifier circuits are used because of the high power they can deliver for the small number of components needed; in this case power to drive a speaker. Radio and television sets often use this circuit for their speaker amplifiers.

Push-pull circuits are used as _____ amplifiers.

- -

power

15. The push-pull circuit illustrated in Frame 14 utilizes transformer coupling for the input and output; however, the circuit could also use capacitive coupling for its input. The center-tapped transformer, T1, functions as a phase-splitter. When a signal is applied to the primary, the secondary of T1 provides two identical outputs 180° out of phase. The signals from the input transformer are applied to the control grids of the vacuum tubes in the push-pull stage, one to each tube.

The input coupling of a push-pull amplifier may be either _____ or _____.

- -

transformer - capacitive (in any order)

16. Notice that both tubes are connected together at their cathodes. The tubes are both grounded-cathode amplifiers. When used in this circuit configuration the tubes must be matched in their conduction characteristics to provide equal amplification.

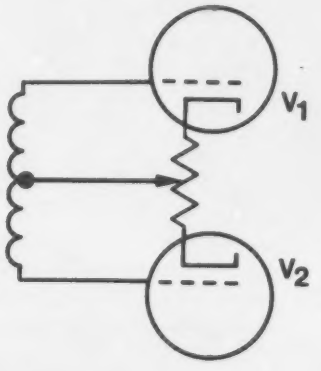
The two signals from the secondary of the input transformer, T1, are (in phase/out of phase).

- -

(out of phase)

17. If both amplifiers conduct equally, and the input signals to each tube are equal, then the output signals from the plate of each tube will be equal in amplitude. These output signals will also be 180° out of phase, because both of the grounded-cathode tubes will invert their input signals.

If the tubes are not matched, an adjustable resistor will have to be added to the cathode circuitry. The resistor must be adjusted so each tube will amplify the same. This adjustment changes the balance of the bias between one tube and the other.

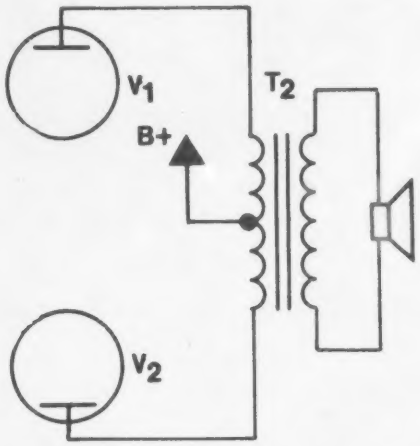


The amplified signals from each tube are equal in _____ but _____ phase.

- -

amplitude - opposite in (180° out of) (or words to that effect) (in that order)

18.



The output signals from the tubes are applied across the primary of the output transformer, T2. When the current from one tube is increasing, the current from the other tube is decreasing. The push-pull action causes the changes in currents to aid each other so that the output of power from the secondary is much higher.

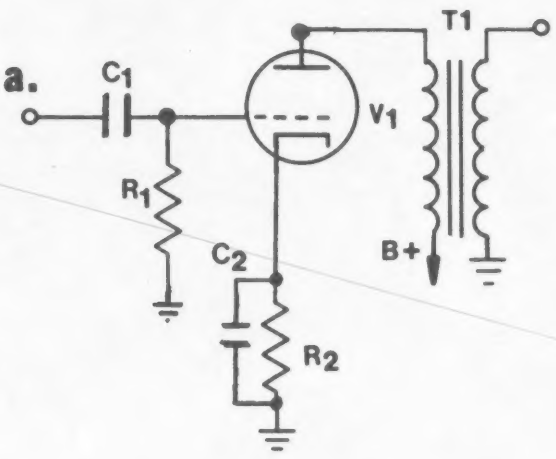
What component could be added to the cathode circuitry to ensure equal conduction? _____

- -

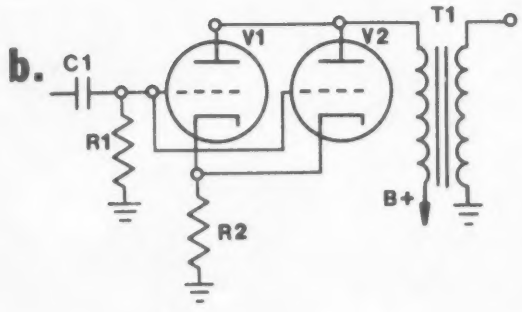
An adjustable resistor.

19. Which of the circuits illustrated below is a push-pull amplifier?

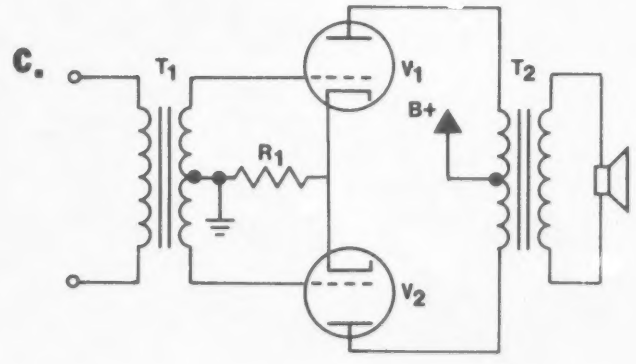
a.



b.



c.



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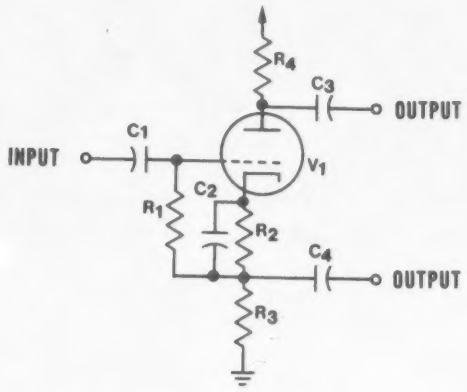
THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.

c.

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 22. OTHERWISE, GO BACK TO FRAME 14 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 19 AGAIN.

20. In the push-pull circuit just studied, a transformer is used as a phase-splitter in the input stage. The function of the center-tapped transformer, T1, is to produce two equal amplitude signals of opposite phase. The following circuit performs the same function, and could be used as an input to the push-pull amplifier.



The Phase-Splitter circuit has just one input signal. The output signals are taken from the plate and the cathode of the tube. The circuit is designed so that the output signals will be nearly equal in amplitude.

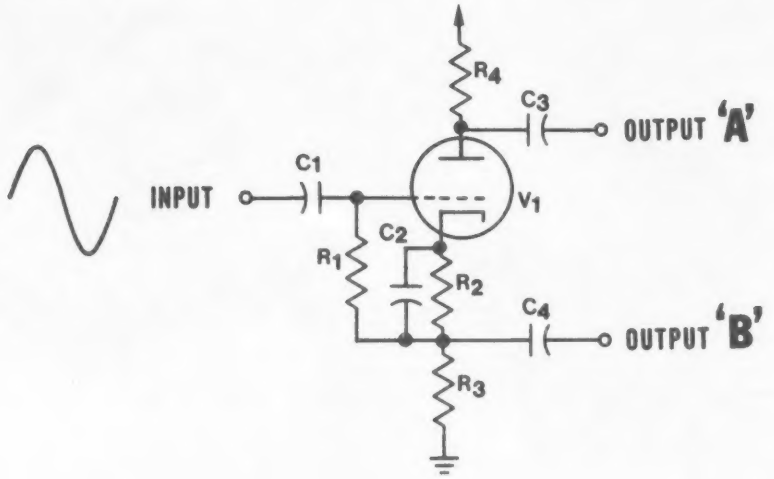
The phase-splitter circuit has (one/two) input and (one/two) output signal(s).

- -

one, two (in that order)

21. With phase inversion between the control grid's input and the plate's output signal, and no inversion between the control grid signal and the cathode signal, the two output signals will be 180° out of phase with respect to each other.

Match the correct sine wave to the proper output location.



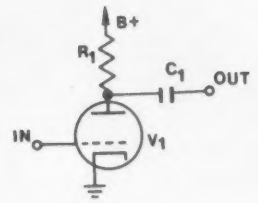
1.

2.

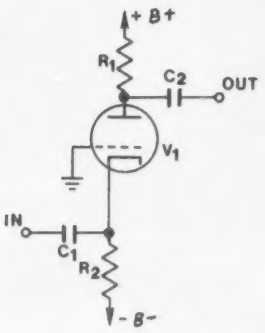
A. 1; B. 2

22. Write the correct name for each of the following circuits on a separate piece of paper.

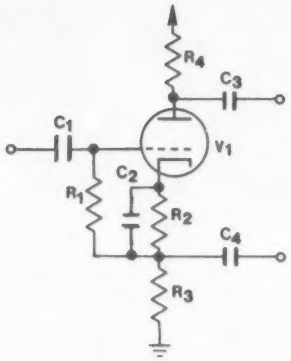
a.



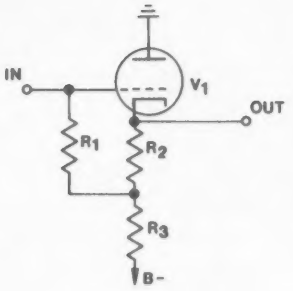
b.



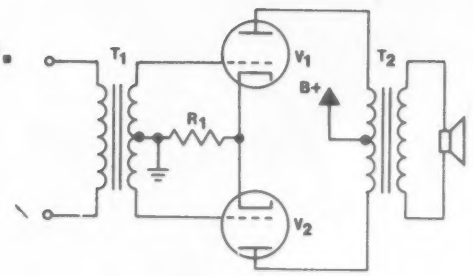
c.



d.



e.



- -

THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.

a. Grounded-cathode	b. Grounded-grid
c. Phase-splitter	d. Cathode-follower (grounded plate)
e. Push-pull	

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

NARRATIVE
LESSON II

Vacuum Tube Circuit Configuration

In Module Twenty One, Transistor Amplifiers, you were introduced to three single-ended amplifier configurations. They are: the common-emitter, the common-base, and the common-collector amplifiers. Each of these circuits is used for a specific function or job. In vacuum tube circuits there is comparable circuitry. This lesson will compare the transistor circuitry you have already studied to the comparable circuitry which uses vacuum tubes.

The first of these circuit configurations is the grounded-cathode (see Figure 1).

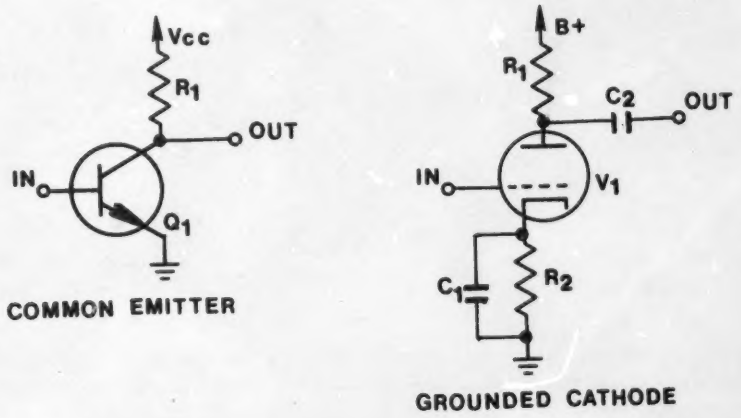


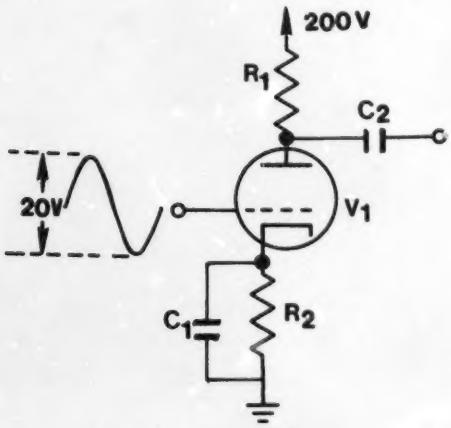
Figure 1

The common-emitter configuration gives us amplification and phase inversion. The grounded-cathode amplifier also gives us amplification and phase inversion. The major differences between the tube and transistor circuits is the power used by the tube. The vacuum tube can also handle larger voltages in its input and output.

The maximum output signal of the grounded-cathode circuit, like the common-emitter amplifier, will depend on the power supply voltage (B+), so, the output signal may have better than 100 volts alternation.

The grounded-cathode configuration has good voltage and power gain.

In the circuit represented below, which output signal would you expect to see from the grounded-cathode vacuum tube amplifier?



a. 100V

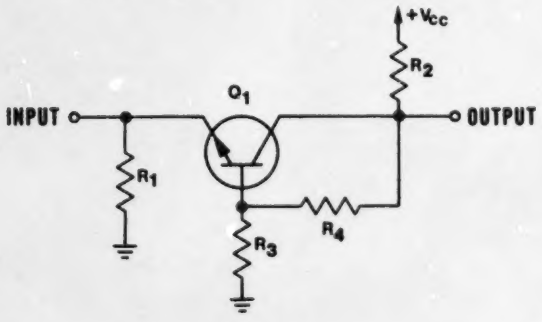
b. 19V

c. 100V

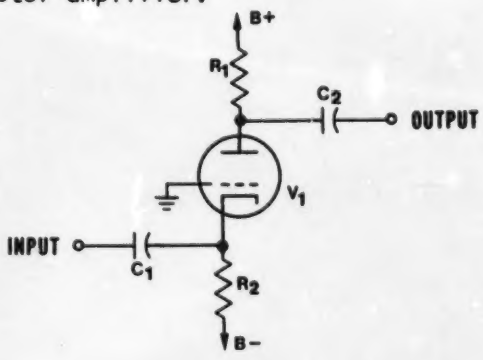
d. 19V

c.

The second circuit configuration is the grounded-grid amplifier. This circuit compares to the common-base transistor amplifier.



COMMON BASE

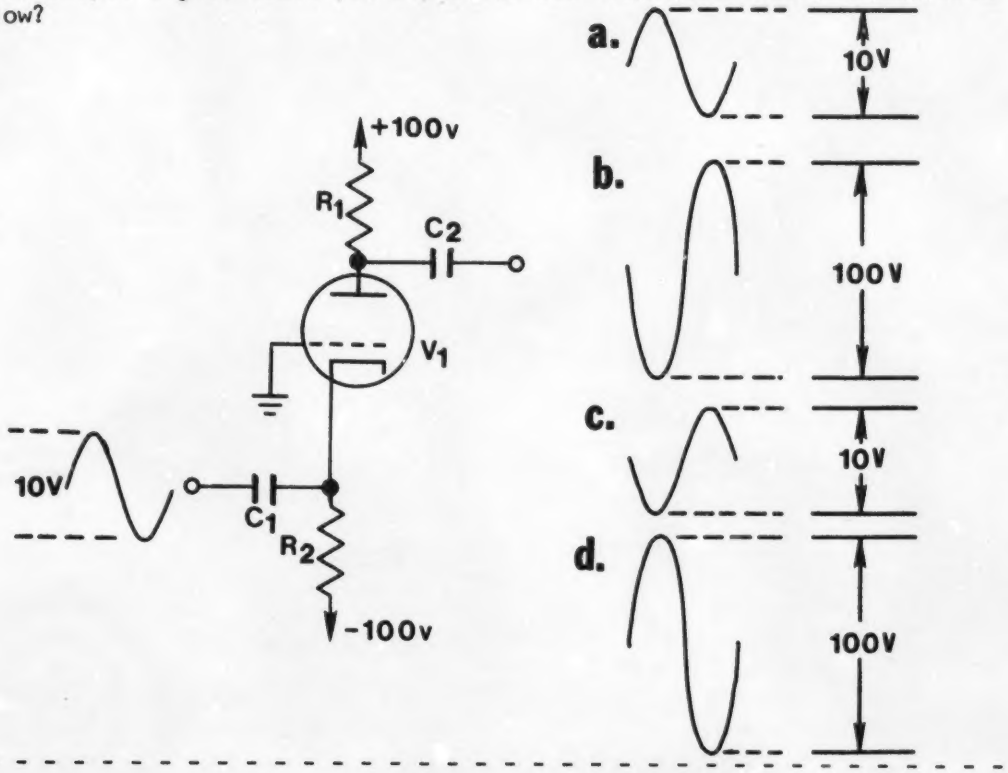


GROUNDED GRID

Figure 2

In the common-base transistor circuit, the input signal is applied to the emitter and the output is taken from the collector. The output signal is amplified without phase inversion. The grounded-grid circuit is comparable to the common-base circuit in that the output signal from the grounded-grid tube amplifier is also amplified without phase inversion. The grounded-grid circuit also has a larger voltage gain than the grounded-cathode circuit.

Which output signal would you expect to see from the circuit illustrated below?



d.

The third and last of the sigle-ended amplifiers is the grounded-plate configuration (see Figure 3). In transistors it would be called common-collector.

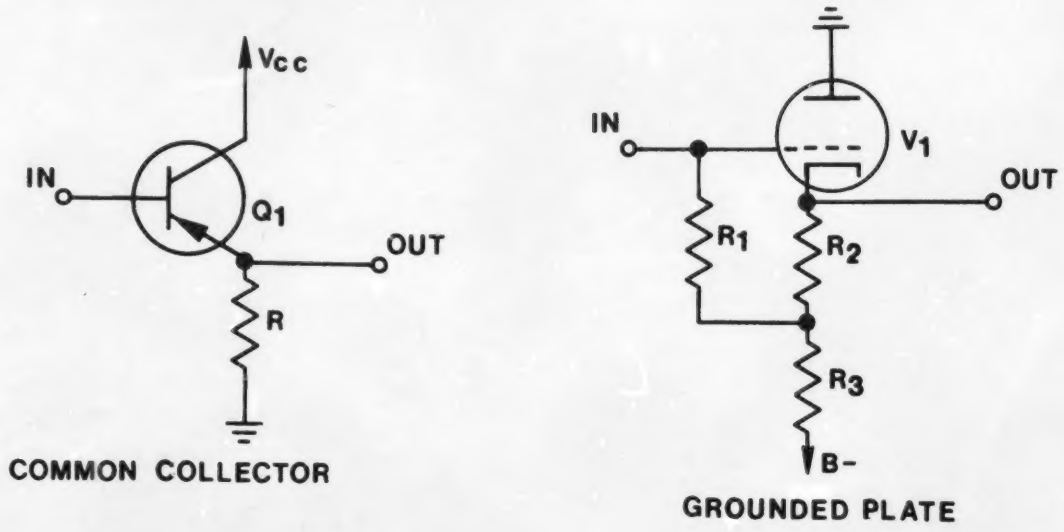
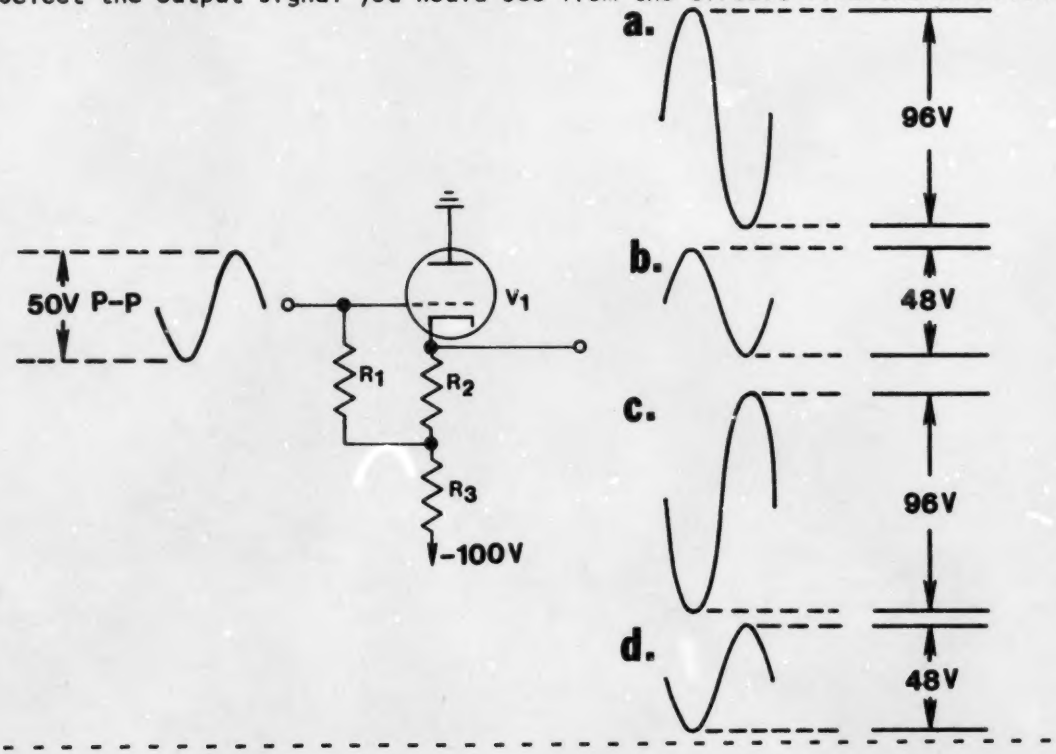


Figure 3

This circuit is generally referred to as a cathode-follower. As you can see the cathode follower's input is applied to the grid, and the output is taken from the cathode. Like the common-collector, the cathode-follower's voltage gain is less than unity (1). This means that the output signal voltage will be slightly less than the input signal voltage. As with the common-collector circuit, the cathode follower will have no phase inversion between input and output signals.

Select the output signal you would see from the circuit illustrated below.



d.

The vacuum tube push-pull circuit (Figure 4), like the transistor push-pull circuit, uses two amplifiers with their cathodes connected together.

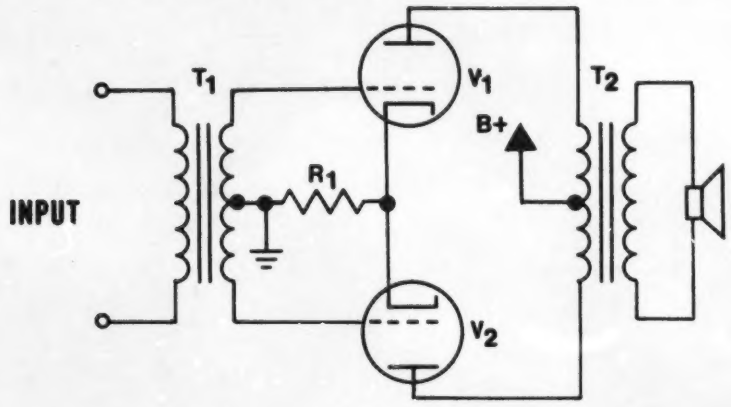


Figure 4

As in the transistor circuit, the tube push-pull amplifier uses transformer coupling for both the input and the output of the circuit. The two tubes will be matched by conduction characteristics. This will ensure that both will be conducting the same amount, thereby amplifying the two input signals to the same level. The two signals from the amplifier's plates will be applied across the output coupling transformer at the same time, but they will be 180° out of phase. The induced signal at the secondary of the transformer will have much more power than a single-ended amplifier can provide.

In the push-pull amplifier, you have two inputs, one to each tube, and one large output. In the phase-splitter (Figure 5), you have the opposite; one input and two outputs. The output signals will be 180° out of phase with each other. The amplitudes of the two output signals are nearly equal because the plate (R4) and cathode (R3) resistors are of equal value.

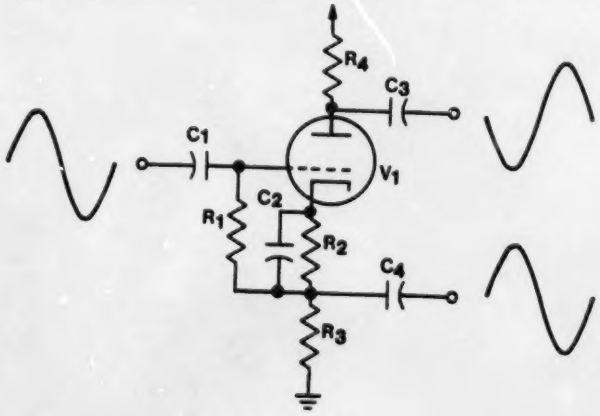
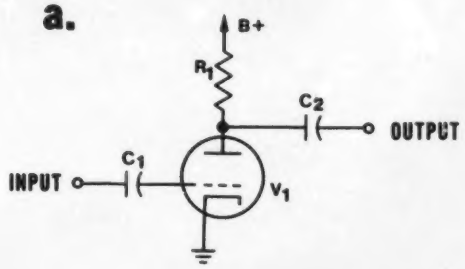


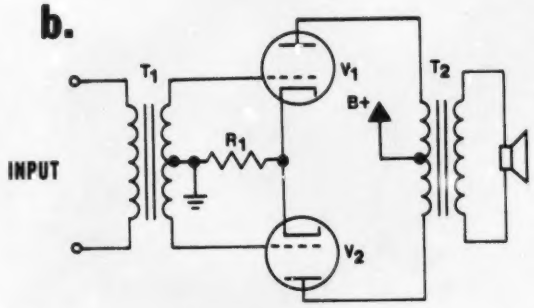
Figure 5

Correctly name each of the following circuits in the spaces provided.

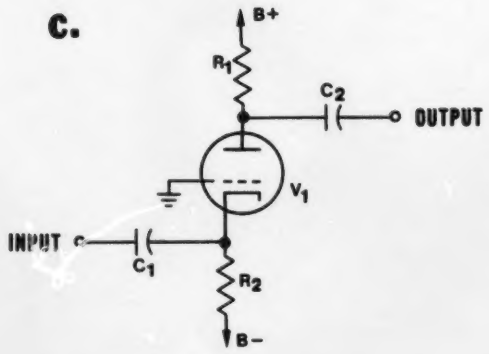
a.



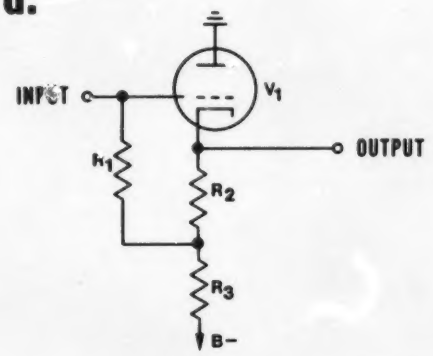
b.



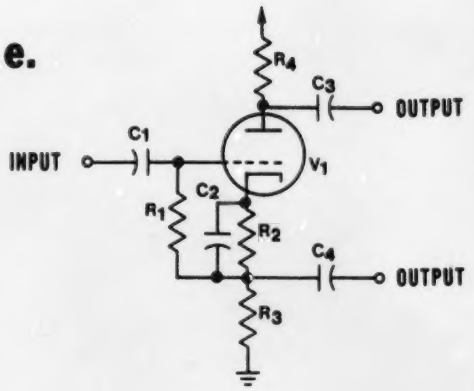
c.



d.



e.



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a. Grounded-cathode; b. Push-pull; c. Grounded-grid;
d. Grounded-plate (cathode follower); e. Phase-splitter.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING SUPERVISOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.